NEWTON'S LAWS OF MOTION

ARISTOTLE'S FALLACY

According to Aristotle, a constant continuous force is required to keep a body in uniform motion. This is called Aristotle's Fallacy.

1. NEWTON'S FIRST LAW OF MOTION (OR GALILEO'S LAW OF INERTIA)

Every body continues its state of rest or uniform motion in a straight line unless compelled by an external force to change its state.

- This law defines the force and states that "force is a factor which can change the state of object."

Definition of force from Newton's first law of motion

"Force is the push or pull which changes or tends to change the state of rest or of uniform motion".

2. FORCE

Any push or pull which either changes or tends to change the state of rest or of uniform motion (constant velocity) of a body is known as force.

Effects of Resultant force :-

A non zero resultant force may produce the following effects on a body :

(i) It may change the speed of the body.

(ii) It may change the direction of motion.

(iii) It may change both the speed and direction of motion.

(iv) It may change the size or/and the shape of the body.

Units for measurement of force :-

Absolute units	**Other units**
(i) N (M.K.S)	kg-wt or kg-f (kg-force)
(ii) dyne (C.G.S)	g-wt or g-f

Relation between above units :-

$$1 \text{ kg-wt} = 9.8 \text{ N}$$
$$1 \text{ g-wt} = 980 \text{ dyne}$$
$$1 \text{ N} = 10^5 \text{ dyne}$$

3. INERTIA

Inertia is the property of a body due to which it opposes any change in its state. Mass of a body is the measure of its inertia of translational motion. It is difficult to change the state of rest or uniform motion of a body of heavier mass and vice-versa.

- Mass of a body is quantitative or numerical measure of a body's inertia.
- Larger the inertia of a body, more will be its mass.

Inertia of rest : It is the inability of a body to change its state of rest by itself.

Examples :

- When we shake a branch of a mango tree, the mangoes fall down.
- When a bus or train starts suddenly, the passengers sitting inside tends to fall backwards.
- When a horse starts off suddenly, its rider falls backwards.
- A coin is placed on cardboard and this cardboard is placed over a tumbler such that coin is above the mouth of tumbler. Now if the cardboard is removed with a sudden jerk, then the coin falls into the tumbler.
- The dust particles in a blanket fall off when it is beaten with a stick.

Inertia of motion : It is the inability of a body to change its state of uniform motion by itself.

Examples :

- When a bus or train stops suddenly, the passengers sitting inside lean forward.
- A person who jumps out of a moving train may fall in the forward.
- A bowler runs with the ball before throwing it, so that his speed of running gets added to the speed of the ball at the time of throw.
- An athlete runs through a certain distance before taking a long jump because the velocity acquired during the running gets added to the velocity of athlete at the time of jump and hence he can jump over a longer distance.
- A ball is thrown in the upward direction by a passenger sitting inside a moving train.

  The ball will fall :-

  - back to the hands of the passenger, if the train is moving with constant velocity.
  - ahead of the passenger, if the train is retarding (slowing down)
  - behind of the passenger, if the train is accelerating (speeding up)

Inertia of direction : It is the inability of a body to change its direction of motion by itself

Examples :

- When a straight running car turns sharply, the person sitting inside feels a force radially outwards.
- Rotating wheels of vehicle throw out mud, mudguard fitted over the wheels prevent this mud from spreading.
- When a knife is pressed against a grinding stone, the sparks produced move in the tangential direction.

4. MOMENTUM

The total quantity of motion possessed by a moving body is known as the momentum of the body. It is the product of the mass and velocity of a body. It is a vector quantity whose direction is along the instantaneous velocity.

momentum $\vec{p} = m\vec{v}$

SI Unit : kg–m/s

Dimension : $[M\,L\,T^{-1}]$

5. NEWTON'S SECOND LAW OF MOTION

According to Newton, the rate of change of momentum of any system is directly proportional to the applied external force and this change in momentum takes place in the direction of the applied force.

$$\vec{F} = \frac{d\vec{p}}{dt} = \frac{d}{dt}(m\vec{v}) \qquad \text{or} \qquad \vec{F} = m\frac{d\vec{v}}{dt} + \vec{v}\frac{dm}{dt} \quad \text{(general form)}$$

If m = constant then $\frac{dm}{dt} = 0$

$$\Rightarrow \boxed{\vec{F} = m\frac{d\vec{v}}{dt} = m\vec{a}}$$

If $\vec{v}$ = constant then $\frac{d\vec{v}}{dt} = 0$

$$\Rightarrow \boxed{\vec{F} = \vec{v}\frac{dm}{dt}}$$ (e.g. conveyor belt, rocket propulsion)

Illustrations

Illustration 1.

A force $\vec{F} = (6\hat{i} - 8\hat{j} + 10\hat{k})\,N$ produces an acceleration of $\sqrt{2}$ m/s^2 in a body. Calculate the mass of the body.

Solution

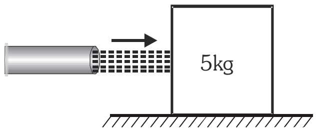
From Newton's IInd law $|\vec{F}| = |m\vec{a}| = ma$

$\Rightarrow$ Acceleration $a = \frac{|\vec{F}|}{m}$ $\qquad \Rightarrow m = \frac{|\vec{F}|}{a} = \frac{\sqrt{6^2 + 8^2 + 10^2}}{\sqrt{2}} = 10\,kg$

Illustration 2.

A 5kg block is resting on a frictionless plane. It is struck by a jet, releasing water at the rate of 3kg/s emerging with a speed of 4m/s. Calculate the initial acceleration of the block.

Solution

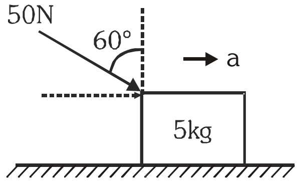


Force exerted on block $F = v\dfrac{dm}{dt} = 4 \times 3 = 12$ N

so acceleration of the block $a = \dfrac{F}{m} = \dfrac{12}{5} = 2.4 m/s^2$

Illustration 3.

A force of 50 N acts in the direction as shown in figure. The block is of mass 5kg, resting on a smooth horizontal surface. Find out the acceleration of the block.



Solution

Horizontal component of the force = 50 sin 60° = $\dfrac{50\sqrt{3}}{2}$

acceleration of the block, a = $\dfrac{\text{component of force in the direction of acceleration}}{\text{mass}} = \dfrac{50\sqrt{3}}{2} \times \dfrac{1}{5} = 5\sqrt{3}\ m/s^2$

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6. IMPULSE

When a large force is applied on a body for a very short interval of time, then the product of force and time interval is known as impulse.

$$d\vec{I} = \vec{F}dt = d\vec{p} \quad \left[\because \frac{d\vec{p}}{dt} = \vec{F}\right]$$

Units of impulse = N–s or kg-m/s.

Dimensions of impulse = [F] [t] = [m] [a] [t] = $[M^1L^1T^{-2}T^1] = [M^1L^1T^{-1}]$

Case-I : If this force is working from time t_1 to t_2, then integrating the above equation, we get -

$$\vec{I} = \int_{t_1}^{t_2} \vec{F}\,dt = \int_{\vec{p}_1}^{\vec{p}_2} d\vec{p} = \vec{p}_2 - \vec{p}_1$$

⇒ Impulse = Change in momentum

Case-II : If a constant or average force acts on body, then :-

$$\vec{I} = \int_{t_1}^{t_2} \vec{F}_{avg}\,dt = \int_{\vec{p}_1}^{\vec{p}_2} d\vec{p} \quad \Rightarrow \quad \vec{I} = \vec{F}_{avg}\int_{t_1}^{t_2} dt = \int_{\vec{p}_1}^{\vec{p}_2} d\vec{p}$$

$$\vec{I} = \vec{F}_{avg}[t]_{t_1}^{t_2} = [\vec{p}]_{\vec{p}_1}^{\vec{p}_2} \quad \Rightarrow \quad \vec{I} = \vec{F}_{avg}(t_2 - t_1) = (\vec{p}_2 - \vec{p}_1)$$

$$\boxed{\vec{I} = \vec{F}_{avg}\,\Delta t = \Delta\vec{p}}$$

6.1 Impulse-Momentum Theorem

The impulse of force is equal to the change in momentum. This relation is known as impulse-momentum theorem.

6.2 Law of Conservation of linear momentum

If net external force on a system is zero then the linear momentum of the system remains constant. According to Newton's IInd Law.

$$\vec{F}_{ext} = \frac{d\vec{p}}{dt}$$

If $\vec{F}_{ext} = \vec{0}$ then

$$\frac{d\vec{p}}{dt} = \vec{0} \quad \Rightarrow \quad \boxed{\vec{p} = \text{constant}} \quad \text{or} \quad \boxed{\vec{p}_{initial} = \vec{p}_{final}}$$

$$\Rightarrow \quad \vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \vec{p}_4 + ...+ \vec{p}_n = \text{constant} \qquad \text{(Conservation of linear momentum)}$$

$$\Rightarrow \quad \Delta(\vec{p}_1 + \vec{p}_2 + ...+ \vec{p}_n) = 0$$

$$\Rightarrow \quad \Delta\vec{p}_1 + \Delta\vec{p}_2 + ...+ \Delta\vec{p}_n = 0$$

for two-particles system $\vec{p}_1 + \vec{p}_2 = \text{constant}$

$$\Delta\vec{p}_1 + \Delta\vec{p}_2 = 0$$

$\boxed{\Delta\vec{p}_1 = -\Delta\vec{p}_2}$ (change in momentum of Ist particle = –change in momentum of IInd particle)

GOLDEN KEY POINTS

Important points about Newton's Second Law of Motion

- Newton's first law of motion defines force and second law of motion measures force. It gives the units, dimensions and magnitude of the force.

  Unit of force = (unit of mass) × (unit of acceleration) = 1kg × 1 m/s^2 = 1N

  1N = 1 kg-m/s^2

  1 dyne = 1 g-cm/s^2

  Dimensions of force :- = [m] [a] = [M^1] [L^{1}T^{-2}] = [M^{1}L^{1}T^{-2}]
- If a particle moves uniformly, means velocity = constant

  $$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d(\text{constant})}{dt} = \vec{0} \qquad \text{So,} \qquad \vec{F} = m\vec{a} = m \times \vec{0} = \vec{0}$$

  It means that, in the absence of external force, a particle moves uniformly. This is Newton's first law of motion. It means that, we can derive mathematically Newton's first law of motion with the help of Newton's second law of motion,
- Accelerated motion is always due to an external force.
- Law of Conservation of Linear Momentum (COLM) is applicable in the direction in which external force is zero, i.e.

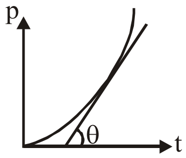
  If $F_x = 0 \Rightarrow \frac{dp_x}{dt} = 0$, then p_x = constant

  If $F_y = 0 \Rightarrow \frac{dp_y}{dt} = 0$, then p_y = constant

  If $F_z = 0 \Rightarrow \frac{dp_z}{dt} = 0$, then p_z = constant

- The slope of momentum-time graph is equal to the force on the particle

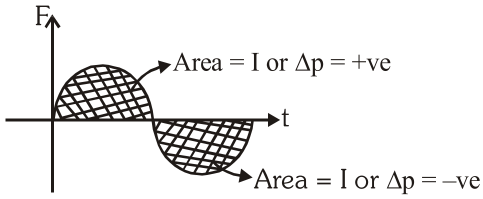
  e.g.



Here, $\boxed{F = \frac{dp}{dt} = \text{slope} = \tan\theta}$

- Area under the force-time graph represents impulse or change in momentum.

  e.g.



Here, $\boxed{I \text{ or } \Delta p = \int F dt = \text{Area under F-t graph}}$

Note :- Since $F_{avg} = \frac{\Delta p}{\Delta t}$

therefore, for a certain momentum change if the time interval is increased, then the average force exerted on body will decrease.

Examples

(i) A cricketer lowers his hands while catching a ball so as to increase the time interval of momentum change consequently the average reaction force on his hands decreases. So he can save himself from getting hurt.

(ii) Shockers are provided in vehicles to avoid jerks.

(iii) Buffers are provided in boggies of train to avoid jerks.

(iv) A person jumping on a hard cement floor receives more injury than a person jumping on muddy or sandy road.

Illustrations

Illustration 4.

A hammer of mass 1 kg moving with a speed of 6 m/s strikes a wall and comes to rest in 0.1 s. Calculate.

(a) impulse of the force (b) average retarding force that stops the hammer.

(c) average retardation of the hammer

Solution

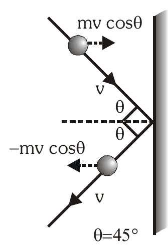
(a) Impulse = $F \times \Delta t = m(v - u) = 1(0 - 6) = -6$ N-s

(b) Average retarding force that stops the hammer $F = \frac{\text{Impulse}}{\text{time}} = \frac{6}{0.1} = 60$ N

(c) Average retardation $a = \frac{F}{m} = \frac{60}{1} = 60 \text{ m/s}^2$

Illustration 5.

A ball of 0.20 kg hits a wall with a velocity of 25 m/s at an angle of 45°. If the ball rebounds at 90° to the direction of incidence, calculate the magnitude of change in momentum of the ball.



Solution

Change in momentum = (– mv cos 45°) – (mv cos 45°) = – 2mv cos 45°

$$|\Delta \vec{p}| = 2mv\cos45° = 2 \times 0.2 \times 25 \times \frac{1}{\sqrt{2}} = 5\sqrt{2} \text{ N-s}$$

Illustration 6.

A cricket ball of mass 150 g is moving with a velocity of 12 m/s and is hit by a bat so that the ball gets turned back with a velocity of 20 m/s. If the duration of contact between the ball and bat is 0.01 s, find the impulse and the average force exerted on the ball by the bat.

Solution

According to given problem change in momentum of the ball

$\Delta p = p_f - p_i = m(v - u) = 150 \times 10^{-3}\ [20 - (-12)]$

So by impulse-momentum theorem, Impulse I = Δp = 4.8 N–s

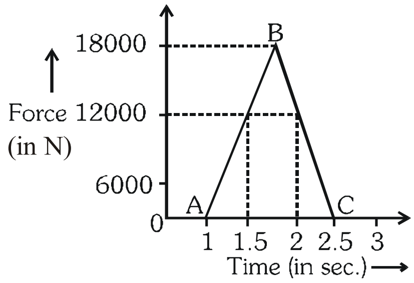
And by time average definition of force in case of impulse $F_{av} = \frac{I}{\Delta t} = \frac{\Delta p}{\Delta t} = \frac{4.80}{0.01} = 480\,N$

Illustration 7.

Figure shows an estimated force–time graph for a base ball struck by a bat. From this curve, determine

(a) Impulse delivered to the ball

(b) Average force exerted on the ball.



Solution

(a) Impulse = Area under F-t curve

$= \text{Area of } \Delta ABC = \frac{1}{2}\ 18000 \times (2.5 - 1)$

$= 1.35 \times 10^4$ kg–m/s

(b) Average force = $\frac{\text{Impulse}}{\text{Time}} = \frac{1.35 \times 10^4}{(2.5 - 1)} = 9000$ N

BEGINNER'S BOX-1

1. A force of 72 dynes is inclined at an angle of 60° to the horizontal, find the acceleration in a mass of 9 g which moves under the effect of this force in the horizontal direction.

2. A constant retarding force of 50N is applied to a body of mass 20 kg moving initially with a speed of 15 m/s. What time does the body take to stop ?

3. A constant force acting on a body of mass 3 kg changes its speed from 2 m/s to 3.5 m/s in 25 s in the direction of the motion of the body. What is the magnitude and direction of the force?

4. A body of mass 5kg is acted upon by two perpendicular forces of 8N and 6N, find the magnitude and direction of the acceleration.

5. A ball of mass 1 kg dropped from 9.8 m height, strikes the ground and rebounds to a height of 4.9 m. If the time of contact between ball and ground is 0.1 s, then find impulse and average force acting on ball.

6. A machine gun fires a bullet of mass 50 gm with velocity 1000 m/s. If average force acting on gun is 200 N then find out the maximum number of bullets fired per minute.

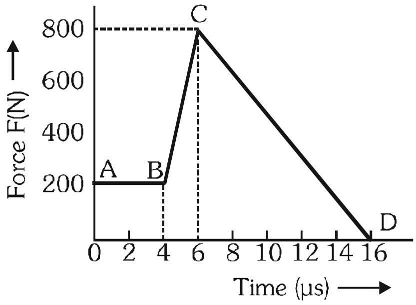
7. A machine gun has a mass of 20 kg. It fires 35 g bullets at the rate of 400 bullets per minute with a speed of 400m/s. What average force must be applied to the gun to keep it in position ?

8. A force of 10N acts on a body for 3 μs. If mass of the body is 5 g, calculate the impulse and the change in velocity.

9. A body of mass 0.25 kg moving with velocity 12 m/s is stopped by applying a force of 0.6 N. Calculate the time taken to stop the body. Also calculate the impulse of this force.

10. A batsman deflects a ball by an angle of 90° without changing its initial speed, which is equal to 54 km/hr. What is the impulse imparted to the ball ? (Mass of the ball is 0.15 kg)

11. The magnitude of the force (in newton) acting on a body varies with time t (in microsecond) as shown in fig. AB, BC and CD are straight line segments. Find the magnitude of the total impulse of the force (in N–s) on the body from t = 4 μs to t = 16 μs.



7. ROCKET PROPULSION

Case-I : If rocket is accelerating upwards, then -

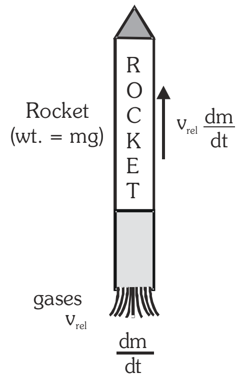
Net upwards force on rocket = ma

$$v_{rel}\frac{dm}{dt} - mg = ma$$

Where v_{rel} is the relative velocity of the ejected mass w.r.t rocket

Case-II : If rocket is moving with constant velocity, then a = 0

$$v_{rel}\frac{dm}{dt} = mg$$



Illustrations

Illustration 8.

A 600 kg rocket is set for a vertical firing. If the exhaust speed of gases is 1000 m/s, then calculate the mass of gas ejected per second to supply the thrust needed to overcome the weight of rocket.

Solution

Force required to overcome the weight of rocket F = mg and thrust needed = $v_{rel}\frac{dm}{dt}$

so $v_{rel}\frac{dm}{dt} = mg \Rightarrow \frac{dm}{dt} = \frac{mg}{v_{rel}} = \frac{600 \times 9.8}{1000} = 5.88$ kg/s

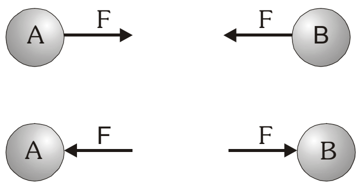
8. NEWTON'S THIRD LAW OF MOTION

According to Newton's third law, to every action, there is always an equal (in magnitude) and opposite (in direction) reaction.

This law is also known as action-reaction law.

Here, $\vec{F}_{12}$ (force on first body due to second body) is equal in magnitude and opposite in direction to $\vec{F}_{21}$ (force on second body due to first body).

$$\boxed{\vec{F}_{12} = -\vec{F}_{21}}$$



The forces between two objects A and B are equal and opposite, whether they are attractive or repulsive.

Important points about Newton's III law

(i) We cannot produce a single isolated force in nature. Forces are always produced in action-reaction pair.

(ii) There is no time gap in between action and reaction. So we cannot say that action is the cause and reaction is its effect. Any one force can be action and the other reaction.

(iii) Action - reaction law is applicable on both the states either at rest or in motion.

(iv) Action and reaction is also applicable between bodies which are not in physical contact.

(v) Action - reaction law is applicable to all the interaction forces eg. gravitational force, electrostatic force, electromagnetic force, tension, friction, viscous force, etc.

(vi) Action and reaction never cancel each other because they act on two different bodies.

Examples : Walking, Swimming, Recoiling of gun when a bullet is fired from it, Rocket propulsion.

GOLDEN KEY POINTS

- **First law** : If no net force acts on a particle, then it is possible to select a set of reference frames, called inertial reference frames, observed from which the particle moves without any change in velocity.
- **Second law** : Observed from an inertial reference frame, the net force on a particle is equal to the rate of change of its linear momentum w.r.t. time : $\frac{d(mv)}{dt}$
- **Third law** : Whenever a particle A exerts a force on another particle B, simultaneously B exerts a force on A with the same magnitude in the opposite direction.
- **Newton's III law can be derived from principle of conservation of linear momentum.**

  If two particles of masses m_1 and m_2 are moving under the action of their mutually interacting forces with each other, such that no external force acts on the system, then

  $\therefore$ momentum of system remains constant.

  i.e. $\Delta\vec{p}_1 + \Delta\vec{p}_2 = 0 \Rightarrow \Delta\vec{p}_1 = -\Delta\vec{p}_2 \Rightarrow \frac{\Delta\vec{p}_1}{\Delta t} = -\frac{\Delta\vec{p}_2}{\Delta t}$

  $$\boxed{\vec{F}_{12} = -\vec{F}_{21}}$$

  Force on 1st due to 2nd = –Force on 2nd due to 1st

- **Inertial and Gravitational mass**

  (1) The ratio of force applied on a particle to its acceleration is known as inertial mass $m_i = \frac{F}{a}$

  (2) The ratio of gravitational force to gravitational acceleration is known as gravitational mass $m_g = \frac{F}{g}$

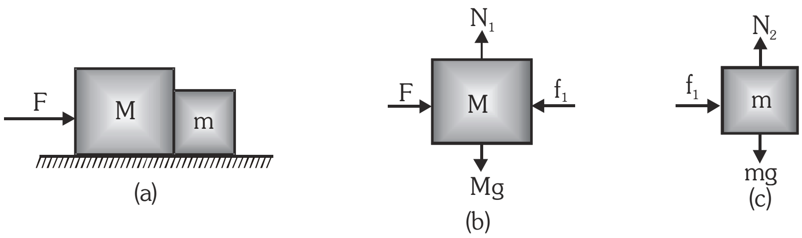
  It is experimentally proved that both masses are equal i.e. $m_i = m_g$

9. FREE BODY DIAGRAM

A diagram showing all external forces acting on an object is called "Free Body Diagram" (F.B.D.)

In a specific problem, we are required to choose a body first and then we access the different forces acting on it, and all the forces are drawn on the body, The resulting diagram is known as free body diagram (FBD).

For example, if two bodies of masses m and M resting on a smooth floor are in contact and a force F is applied on M from the left as shown in figure (a), the free body diagrams of M and m will be as shown in figures (b) and (c).



Important Point :

Two forces in Newton's third law never occur in the same free–body diagram. This is because a free–body diagram shows forces acting on a single object, and the action–reaction pair in Newton's third law always act on different objects.

10. NORMAL REACTION

When a stationary body is placed on a surface then, that surface exerts a contact force on that body which is ***perpendicular to the surface and towards the body***. This force is known as Normal Reaction

e.g. A block of mass "m" is placed on a horizontal table. Then the forces exerted on it are :

(1) Downward gravitational force of attraction on body due to earth, means weight of the block (=mg).

(2) Upward normal reaction exerted by the surface of table on the block.

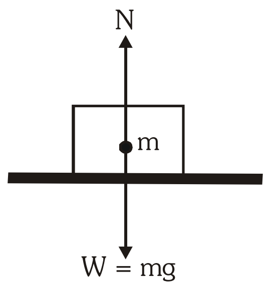
Since the body is in equilibrium, therefore net force on it is zero.

$$\therefore \vec{N}+\vec{W}=\vec{0}$$

$$\vec{N} = -\vec{W}$$

$$N = W \quad [\because |\vec{N}| = |-\vec{W}|]$$

$$\therefore \boxed{N=mg} \quad [\because W = mg]$$



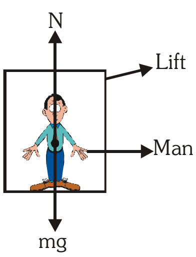
10.1 Effective or Apparent weight of a man in lift

Case-I : If the lift is at rest or moving uniformly (a = 0), then

$$N = mg$$

$$\text{So, } W_{app} = W_{actual}$$

$$\boxed{\begin{array}{l} W_{app} = N \\ W_{actual} = mg \end{array}}$$



Case-II : If the lift is accelerating upwards, then -

Net upward force on man = ma

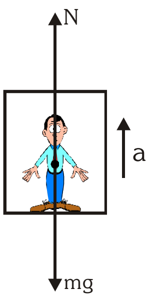
$$N - mg = ma$$

$$N = mg + ma$$

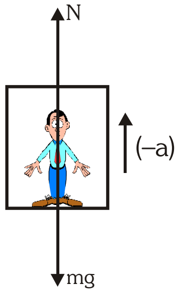
$$\therefore N = m(g + a)$$

$$\boxed{W_{app} \text{ or } N = m(g + a)}$$

So, $W_{app} > W_{actual}$



Case-III : If the lift is retarding upwards, then



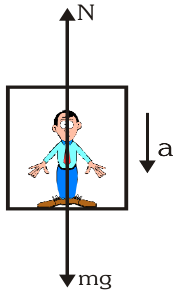
$N - mg = m(-a)$

$N = mg - ma$

$\therefore \quad \boxed{W_{app} \text{ or } N = m(g - a)}$

So, $W_{app} < W_{actual}$

Case-IV : If the lift is accelerated downwards, then -



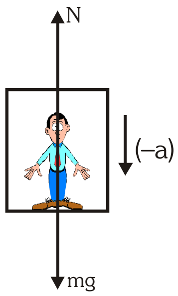
$mg - N = ma$

$N = mg - ma$

$\boxed{W_{app} \text{ or } N = m(g - a)}$

So, $W_{app} < W_{actual}$

Case-V : If the lift is retarding downwards, then -



$mg - N = m(-a)$

$mg - N = -ma$

$N = ma + mg$

$\boxed{W_{app} \text{ or } N = m(g + a)}$

So, $W_{app} > W_{actual}$

Two Special Cases of downward acceleration (IV Case)

I Special Case :- If the lift is falling freely, it implies that its acceleration is equal to the acceleration due to gravity. i.e. $a = g$, then -

$W_{app.} = m(g-a) = m(g-g) = m \times 0 = 0$

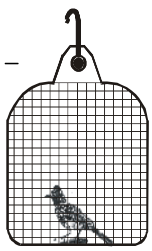
$\therefore \quad W_{app.} = 0$

It means the man will feel weightless. This condition is known as Condition of Weightlessness.

The apparent weight of any freely falling body is zero.

II Special Case :- If the lift is accelerating downwards with an acceleration which is greater than 'g', then the man will move up with respect to the lift and stick to the ceiling.

10.2 Bird-Cage Problem :



I. A bird is sitting on the base in an air tight cage. Now, if the bird starts flying, then –

(i) Weight of system will not change, if the bird flies with constant velocity.

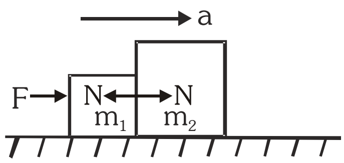
(ii) Weight of system will increase, if the bird flies with upward acceleration.

(iii) Weight of system will decrease, if the bird flies with downward acceleration.

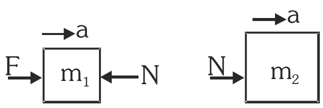
II. A bird is sitting on the base in a wire cage. Now if the birds flies upward its weight will decrease in all the cases.

11. MOTION OF BODIES IN CONTACT (CONTACT FORCE)

Two bodies in contact :



Free body diagrams :



$F - N = m_1 a$ .....(1)

$N = m_2 a$ .....(2)

On adding the above equations

$F = m_1a + m_2a$

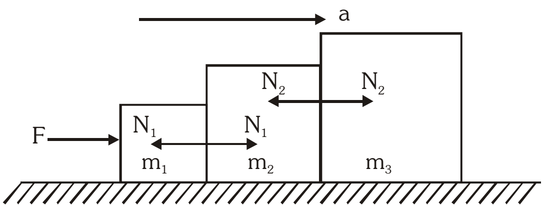
$F = a(m_1+m_2)$

$\Rightarrow \boxed{a = \dfrac{F}{m_1+m_2}}$ ....(3) OR $\boxed{a = \dfrac{F_{net}}{m_{total}}}$

putting the value of 'a' from equation (3) in (2), we get

$\boxed{N = \dfrac{m_2F}{m_1+m_2}}$ (here N = contact force)

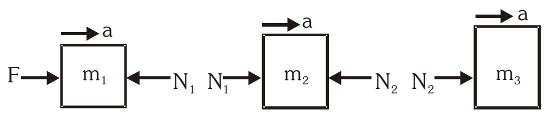
Three bodies in contact :



$F - N_1 = m_1 a$ ....(1)

$N_1 - N_2 = m_2 a$ ....(2)

$N_2 = m_3 a$ ....(3)



On adding the above equations

$F = m_1a + m_2a + m_3a$

$F = a(m_1+m_2+m_3)$

$\Rightarrow \boxed{a = \dfrac{F}{m_1+m_2+m_3}}$ ....(4) or $\boxed{a = \dfrac{F_{Net}}{m_{total}}}$

Putting the value of 'a' from equation (4) in (3), we get

$\boxed{N_2 = \dfrac{Fm_3}{m_1+m_2+m_3}}$

Putting the value of 'a' from (4) in (1);

$F - m_1a = N_1$

$N_1 = F - \dfrac{Fm_1}{m_1+m_2+m_3}$ $\Rightarrow \boxed{N_1 = \dfrac{(m_2+m_3)F}{m_1+m_2+m_3}}$

Illustrations

Illustration 9.

Consider a box of mass 10 kg resting on a horizontal table and acceleration due to gravity to be 10 m/s^2.

(a) Draw the free body diagram of the box.

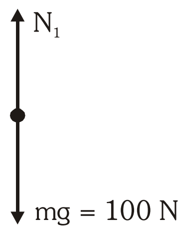
(b) Find value of the force exerted by the table on the box.

(c) Find value of the force exerted by the box on the table.

(d) Does force exerted by table on the box and weight of the box form third law action-reaction pair?

Solution

(a) N_1 : Force exerted by table on the box.



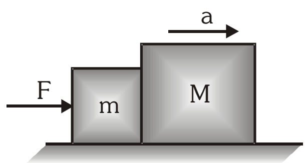
(b) The block is in equilibrium. $\sum \vec{F} = \vec{0} \Rightarrow mg - N_1 = 0 \Rightarrow N_1 = 100 \text{ N}$

(c) N_1 = 100 N : Because force by table on the box and force by box on table make Newton's third law pair.

(d) No

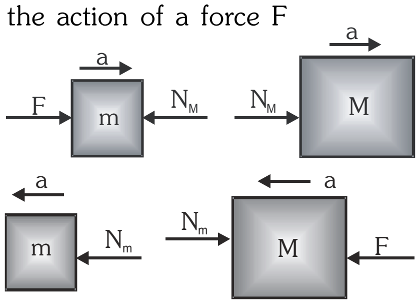
Illustration10.

Two blocks of masses m = 2 kg and M = 5 kg are in contact on a frictionless table. A horizontal force F (= 35 N) is applied to m. Find the force of contact between the blocks. Will the force of contact remain same if F is applied to M ?



Solution

As the blocks are rigid both will move with same acceleration under the action of a force F



$$a = \frac{F}{m+M} = \frac{35}{2+5} = 5 \text{ m/s}^2$$

Force of contact $N_M = Ma = 5 \times 5 = 25$ N

If the force is applied to M then its action on m will be

$N_m = ma = 2 \times 5 = 10$ N.

Note :- From this problem it is clear that acceleration does not depend on the fact that whether the force is applied to m or M, but force of contact does.

Illustration 11.

A spring weighing machine inside a stationary lift reads 50 kg when a man stands on it. What would happen to the scale reading if the lift is moving upward with (i) constant velocity, and (ii) constant acceleration?

Solution

(i) In the case of constant velocity a = 0

Therefore, N = mg so $W_{app} = W_{act}$

hence reading = 50 kg

(ii) In case with upward acceleration

$$N - mg = ma$$

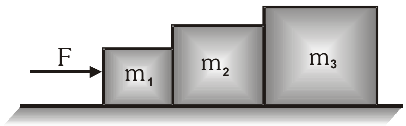
So $N = mg + ma = m(g + a)$

So $W_{app.} > W_{act}$

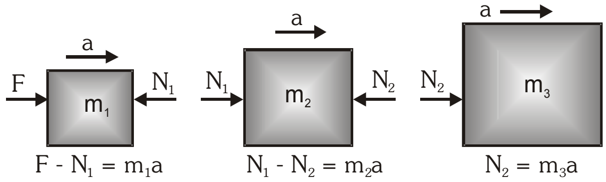
Hence scale reading will be $= \dfrac{50(g+a)}{g} = 50\left(1+\dfrac{a}{g}\right)$ kg.

Illustration 12.

Three blocks of masses m_1 = 1 kg, m_2 = 1.5 kg and m_3 = 2 kg are in contact with each other on a frictionless surface as shown in fig. Find the (a) horizontal force F needed to push the blocks as a single unit with an acceleration of 4 m/s² (b) resultant force on each block and (c) magnitude of contact forces between the blocks.



Solution



(a) $F = (m_1 + m_2 + m_3)\, a$

$= (1 + 1.5 + 2) \times 4$

$= 4.5 \times 4 = 18$ N

(b) For m_1

$F - N_1 = m_1 a = 1 \times 4$

$\Rightarrow F - N_1 = 4$ N ......(i)

for m_2,

$N_1 - N_2 = m_2\, a = 1.5 \times 4 = 6$

$\Rightarrow N_1 - N_2 = 6$N ......(ii)

for m_3,

$N_2 = m_3 a = 2 \times 4$

$\Rightarrow N_2 = 8$N ......(iii)

(c) Contact force between m_2 and m_3 is $N_2 = 8$ N

and contact force between m_1 and m_2 is $N_1 = N_2 + 6 = 8 + 6 = 14$N.

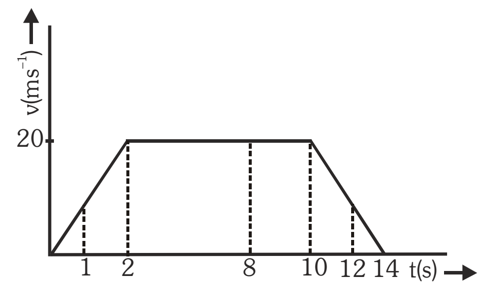
BEGINNER'S BOX-2

1. A person of mass M kg is standing on a lift. If the lift moves vertically upwards according to given v-t graph then find out the weight of man at the following instants : (g = 10 m/s²)

(i) t = 1 second

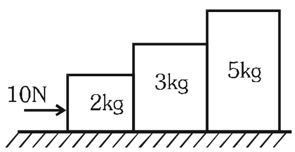
(ii) t = 8 seconds

(iii) t = 12 seconds

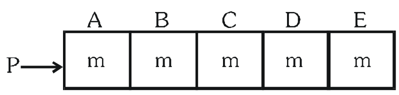


2. Find the acceleration of the system and the contact force between

(i) 2kg and 3 kg blocks (ii) 3kg and 5 kg blocks



3. Calculate : (i) a_{system} (ii) F_{DE} (ii) F_{CD} (iv) F_{BC} (v) F_{AB} corrosponding to the following diagram.



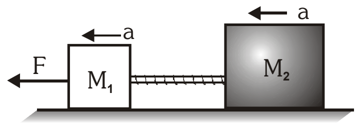
12. SYSTEM OF MASSES TIED BY STRINGS

12.1 Tension in a String

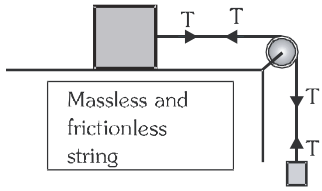
It is the intermolecular forces between the molecules of a string,which become active when the string is streched. Important points about the tension in a string :

(a) Force of tension act on a body in the direction away from the point of contact or tied end of the string.

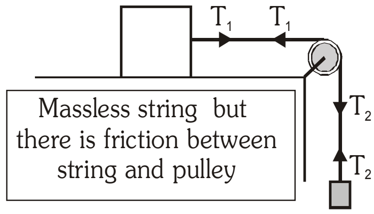
(b) String is assumed to be inextensible so that the magnitude of accelerations of the blocks tied to the strings are always same.



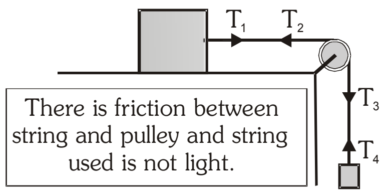
(c) (i) If the string is massless and frictionless, tension throughout the string remains same.



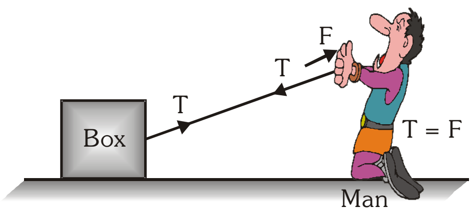
(ii) If the string is massless but not frictionless, at every contact tension changes.



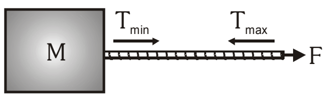
(iii) If the string is not light, tension at each point of the string will be different depending on the acceleration.



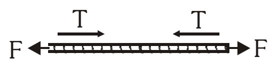
(d) If a force is directly applied to a string, say a man is pulling a string from the other end with some force, then tension will be equal to the applied force irrespective of the motion of the pulling agent, irrespective of whether the box moves or not, man moves or not.



(e) String is assumed to be massless unless stated, hence tension in it remains the same every where and equal to the applied force. However, if a string has a mass, tension at different points will be different being maximum (= applied force) at the end through which force is applied and minimum at the other end connected to a body.



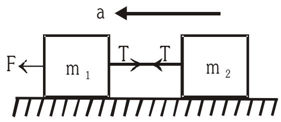
(f) In order to produce tension in a string two equal and opposite stretching forces must be applied. The tension thus produced is equal in magnitude to either applied force (i.e., $T = F$) and is directed inwards opposite to F.



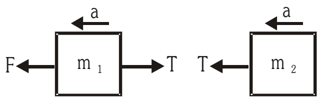
(g) Every string can bear a maximum tension, i.e. if the tension in a string is continuously increased it will break beyond a certain limit. The maximum tension which a string can bear without breaking is called its "breaking strength". It is finite for a string and depends on its material and dimensions.

12.2 Motion of Connected Bodies

- **Two Connected Bodies :**



Free body diagram :-



$F - T = m_1 a$ ....(1)

$T = m_2 a$ ....(2)

On adding the above equations

$F = m_1a + m_2a$

$F = a\,(m_1+m_2)$

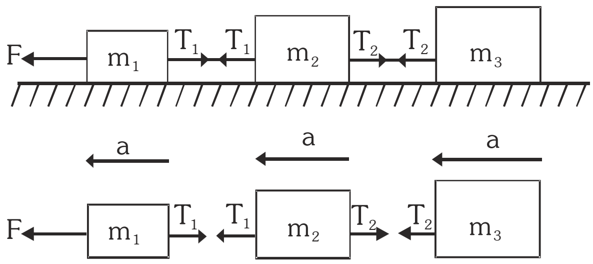
$$\boxed{a = \frac{F}{m_1 + m_2}} \quad ...(3) \quad \text{Or} \quad \boxed{a = \frac{F_{net}}{m_{total}}}$$

Putting the value of 'a' from equation (3) in (2), we get -

$$\boxed{T = \frac{m_2F}{m_1 + m_2}}$$

Three Connected Bodies :

Free body diagrams :-



$F - T_1 = m_1a$ .....(1)

$T_1 - T_2 = m_2a$ .....(2)

$T_2 = m_3a$ .....(3)

On adding above equations

$F = (m_1 + m_2 + m_3)\,a$

$$\therefore \quad \boxed{a = \frac{F}{m_1 + m_2 + m_3}} \quad \text{or} \quad \boxed{a = \frac{F_{net}}{m_{total}}}$$

Put the value of 'a' in equation (1)

$T_1 = F - m_1a$

$$\Rightarrow \quad T_1 = F - \frac{m_1F}{m_1 + m_2 + m_3} = \frac{m_1F + m_2F + m_3F - m_1F}{m_1 + m_2 + m_3}$$

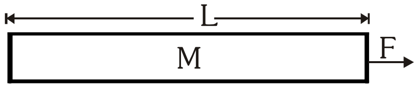
$$\boxed{T_1 = \frac{(m_2 + m_3)F}{m_1 + m_2 + m_3}}$$

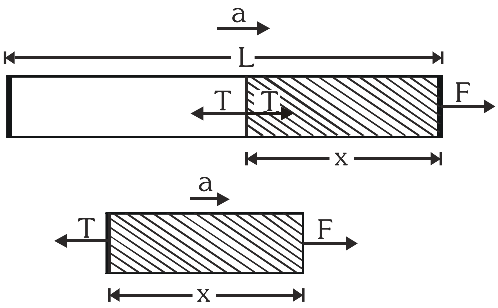
Similarly, putting the value of 'a' in equation (3)

$$\boxed{T_2 = \frac{m_3F}{m_1 + m_2 + m_3}}$$

12.3 Tension in a Rod

Given





Mass of Rod $= M$

Length of Rod $= L$

$F - T = ma$

$\Rightarrow T = F - ma$

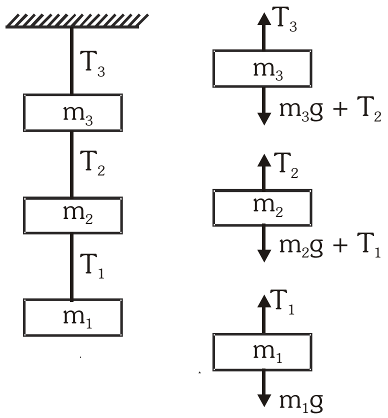
$\Rightarrow T = F - m\dfrac{F}{M} \qquad \left(\because a = \dfrac{F}{M}\right)$

$\because$ Mass of length 'L' $= M$ $\quad\therefore$ Mass of unit length $= \dfrac{M}{L}$ $\quad\therefore$ Mass (m) of length 'x' $= \dfrac{M}{L}x$

Put this value of 'm' in equation (1)

$$T = F - \left(\frac{M}{L}x\right)\frac{F}{M} \Rightarrow \boxed{T = F\left(1 - \frac{x}{L}\right)}$$

12.4 Bodies Hanging Vertically



Since all the bodies are in equilibrium, therefore net force on each body is zero

$T_1 = m_1g$ ....(1)

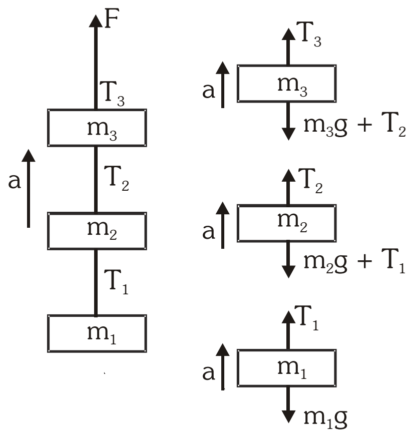
$T_2 = T_1 + m_2g$

$\Rightarrow T_2 = (m_1 + m_2)g$ ....(2)

$T_3 = T_2 + m_3g$

$\Rightarrow T_3 = (m_1 + m_2 + m_3)g$

12.5 Bodies Accelerating Vertically Upwards



For m_1 $\quad T_1 - m_1g = m_1a$

$\Rightarrow \quad T_1 = m_1(g+a)$ ....(1)

For m_2 $\quad T_2 - m_2g - T_1 = m_2a$

$\Rightarrow \quad T_2 = m_2a + m_2g + T_1$

$\Rightarrow \quad T_2 = m_2(g + a) + m_1(g + a)$ (from equation 1)

$\Rightarrow \quad T_2 = (m_1 + m_2)(g + a)$ ....(2)

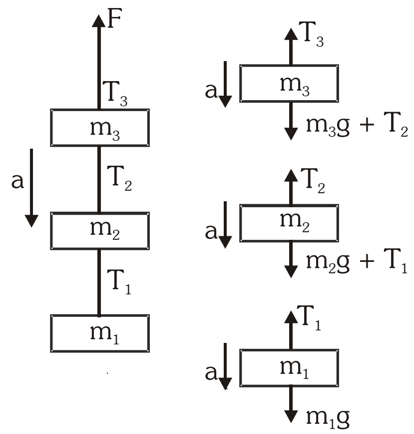
For m_3 $\quad F = T_3$ and $T_3 - m_3g - T_2 = m_3a$

$\Rightarrow \quad T_3 = T_2 + m_3g + m_3a$

$\Rightarrow \quad T_3 = (m_1 + m_2)(g + a) + m_3(g + a)$ (from equation 2)

$\Rightarrow \quad T_3 = (m_1 + m_2 + m_3)(g + a)$ ....(3)

12.6 Bodies Accelerating Vertically Downwards



For m_1 $\quad m_1g - T_1 = m_1a$

$\Rightarrow \quad T_1 = m_1 (g - a) \quad ....(1)$

For m_2 $\quad m_2g + T_1 - T_2 = m_2a$

$\Rightarrow \quad T_2 = m_2g - m_2a + T_1$

$\Rightarrow \quad T_2 = m_2 (g - a) + m_1 (g - a)$ (from equation 1)

$\Rightarrow \quad T_2 = (m_1 + m_2) (g - a) \quad ....(2)$

For m_3 $\quad F = T_3$ and $m_3g + T_2 - T_3 = m_3a$

$\Rightarrow \quad T_3 = m_3g - m_3a + T_2$

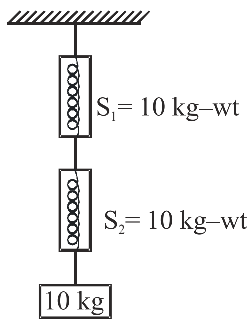
$\Rightarrow \quad T_3 = m_3 (g - a) + (m_1 + m_2) (g - a)$ (from equation 2)

$\Rightarrow \quad T_3 = (m_1 + m_2 + m_3) (g - a) \quad ....(3)$

GOLDEN KEY POINTS

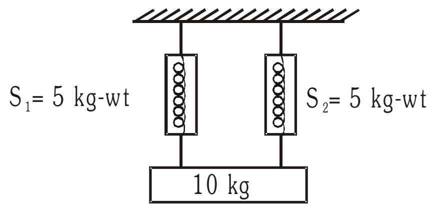
- If several spring balances are connected in series, then the reading of each balance is the same and is equal to the applied load (Note : Spring balances have negligible mass so they are assumed massless)

e.g.



- If several spring balances are connected in parallel and symmetrically to the load, then the applied load is equally divided in all the balances; so the reading of each balance will be $= \dfrac{\text{applied Load}}{\text{no. of balances}}$

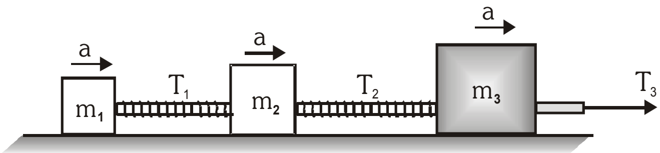
e.g.



Illustrations

Illustration 13.

Three blocks, are connected by strings as shown in the figure below, and are pulled by a force T_3 = 120 N. If m_1 = 5 kg, m_2 = 10 kg and m_3 = 15 kg. Calculate the acceleration of the system and tensions T_1 and T_2.



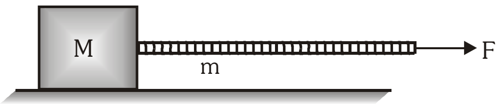
Solution

(i) Acceleration of the system $a = \dfrac{F}{m_1 + m_2 + m_3} = \dfrac{120}{5+10+15} = 4\ m/s^2$

(ii) $T_1 = m_1 a = 5 \times 4 = 20$ N $\qquad T_2 = (m_1 + m_2)a = (5 + 10)\ 4 = 60$ N

Illustration 14.

A block of mass M is pulled along a horizontal frictionless surface by a rope of mass m as shown in fig. A horizontal force F is applied to one end of the rope. Find the (i) Acceleration of the rope and the block (ii) Force that the rope exerts on the block. (iii) Tension in the rope at its mid point.

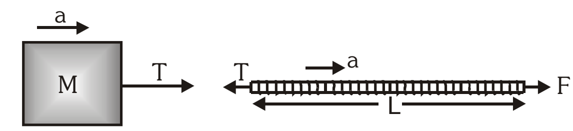


Solution

(i) Acceleration $a = \dfrac{F}{(m+M)}$

(ii) Force exerted by the rope on the block is

$$T = Ma = \frac{M.F}{(m+M)}$$



FBD of block

FBD of rope

(iii) $T_1 = \left(\dfrac{m}{2} + M\right)a = \left(\dfrac{m+2M}{2}\right)\left(\dfrac{F}{m+M}\right)$

Tension in rope at midpoint is $T_1 = \dfrac{(m+2M)F}{2(m+M)}$

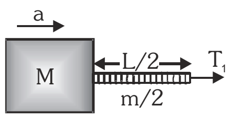
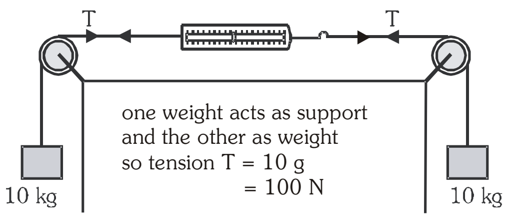


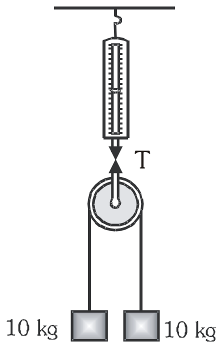
Illustration 15.

The system shown in fig. is in equilibrium. If the spring balance is calibrated in newtons, what does it record in each case? (g = 10 m/s²)

Solution



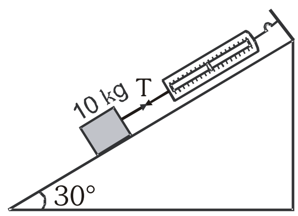
(A)



(B)

$T = 2\times10 \times g = 2 \times 10 \times 10$

$= 200$ N



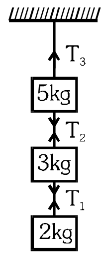
(C)

$T = 10 \times 10 \times \sin 30°$

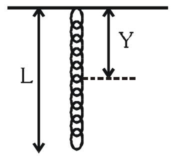
$= 10 \times 10 \times ½ = 50$ N

BEGINNER'S BOX-3

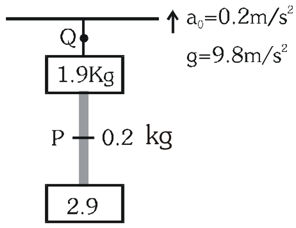
1. In the given figure determine $T_1 : T_2 : T_3$



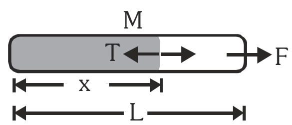
2. Find the tension in the chain at a distance Y from the support.
Mass of chain is M.



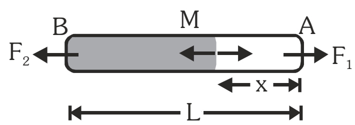
3. Calculate T_P and T_Q (P is mid point)



4. A uniform rope of mass M and length L is placed on a smooth horizontal surface. A horizontal force F is acting at one end of rope. Calculate the tension in the rope at a distance x as shown.

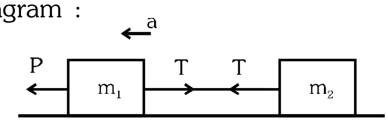


5. Calculate the tension T in the rope at a distance x from end A in the following diagram assuming $F_1 > F_2$.

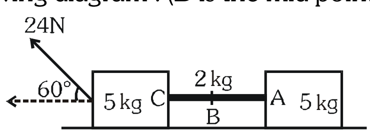


6. A man in a lift carrying a 5 kg bag. If the lift moves vertically downwards with g/2 acceleration. Find the tension in the handle of the bag.

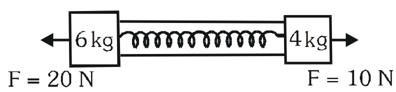
7. Calculate T for the following diagram :



8. Calculate T_A, T_B, T_C for the following diagram : (B is the mid point of rope)



9. A dynamometer is attached to two blocks of masses 6 kg and 4 kg.Forces of 20 N and 10 N are applied on the blocks as shown in figure. Find the dynamometer reading in the steady state.



13. PULLEY SYSTEMS

- Ideal pulley is considered massless and frictionless.
- Ideal string is massless and inextensible.
- A pulley may change the direction of force in the string but not the tension.

> The only function of pulley (which has no friction on its axle to retard rotation) is to change the direction of force through the cord that joins the two blocks.

Some Cases of Pulley

Case I

$m_1 = m_2 = m$

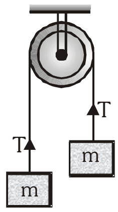
Tension in the string

$T = mg$

Acceleration 'a' = zero

Reaction at the point of suspension of the pulley or thrust on pulley.

$R = 2T = 2\,mg.$



Case II

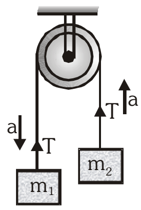
$m_1 > m_2$

now for mass m_1,

$m_1\,g - T = m_1 a$ ....(i)

for mass m_2

$T - m_2\,g = m_2\,a$ ....(ii)



adding (i) and (ii)

$$a = \frac{(m_1 - m_2)}{(m_1 + m_2)}g \text{ and } T = \frac{2m_1m_2}{(m_1+m_2)}g = \frac{2W_1W_2}{W_1 + W_2}$$

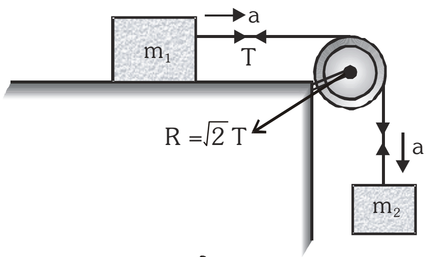
$$\boxed{\text{acceleration } = \frac{\text{net pulling force}}{\text{total mass to be pulled}}}$$

$$\boxed{\text{Tension } = \frac{2 \times \text{Product of masses}}{\text{Sum of masses}}g}$$

Reaction at the suspension point of pulley (or Thrust on pulley)

$$R = 2T = \frac{4m_1m_2g}{(m_1 + m_2)} = \frac{4W_1W_2}{W_1+W_2}$$

Case III :



For mass m_1 : $T = m_1\,a$

For mass m_2 : $m_2g - T = m_2\,a$

$$\text{acceleration } a = \frac{m_2g}{(m_1 + m_2)} \text{ and } T = \frac{m_1m_2}{(m_1+m_2)}g$$

Reaction at suspension point of pulley $R = \sqrt{2}T$

Case IV : $(m_1 > m_2)$

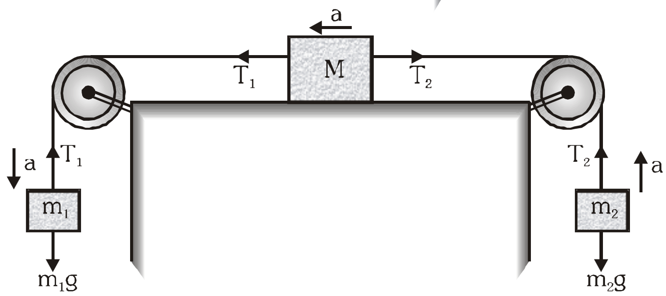
$m_1g - T_1 = m_1a$ (i)

$T_2 - m_2g = m_2a$ (ii)

$T_1 - T_2 = Ma$ (iii)

adding (i), (ii) and (iii)

$$a = \frac{(m_1 - m_2)}{(m_1 + m_2 + M)}g$$



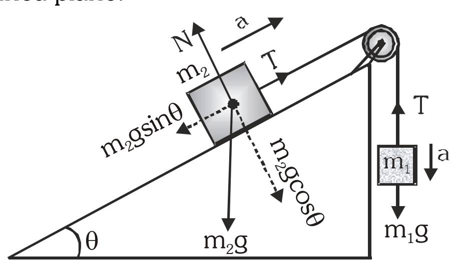
Case V : Mass suspended over a pulley along with another on an inclined plane.

For mass m_1 : $m_1g - T = m_1\,a$

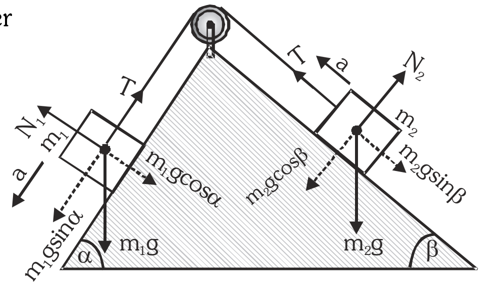
For mass m_2 : $T - m_2g\sin\theta = m_2\,a$

$$\text{acceleration } a = \frac{(m_1 - m_2\sin\theta)}{(m_1 + m_2)}g$$

$$T = \frac{m_1m_2(1 + \sin\theta)}{(m_1 + m_2)}g$$



Case VI : Masses m_1 and m_2 are connected by a string passing over a pulley $m_1\sin\alpha > m_2\sin\beta$



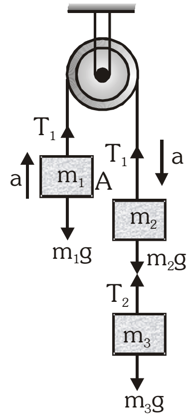
$m_1g\sin\alpha - T = m_1a$ ....(i)

$T - m_2g\sin\beta = m_2a$ ....(ii)

After solving equation (i) and (ii)

Acceleration $a = \dfrac{(m_1\sin\alpha - m_2\sin\beta)}{(m_1 + m_2)}g$

Tension $T = \dfrac{m_1m_2(\sin\alpha + \sin\beta)}{(m_1 + m_2)}g$



Case VII : For mass m_1 : $T_1 - m_1g = m_1a$

For mass m_2 : $m_2g + T_2 - T_1 = m_2a$

For mass m_3 : $m_3g - T_2 = m_3a$

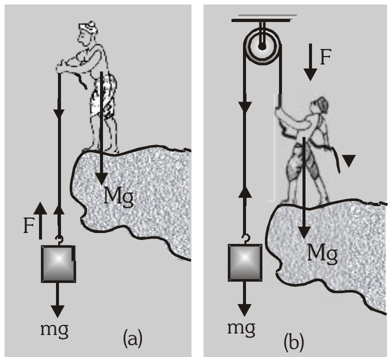
$\Rightarrow \quad a = \dfrac{(m_2 + m_3 - m_1)}{(m_1 + m_2 + m_3)}g$

we can calculate tensions T_1 and T_2 from above equations

Illustrations

Illustration 16.

A block of mass 25 kg is raised in two different ways by a 50 kg man as shown in fig. What is the action in the two cases ? If the floor yields to a normal force of 700 N, which mode should the man adopt to lift the block without the yielding of the floor ?



(a) (b)

Solution

Mass of the block, m = 25 kg ;

mass of the man, M = 50 kg

Force applied to lift the block

$F = mg = 25 \times 9.8 = 245$ N

Weight of the man,

$Mg = 50 \times 9.8 = 490$ N

(a) When the block is raised by the man by applying a force F in the upward direction, reaction being equal and opposite to F will act on the floor in addition to the weight of the man.

$\therefore$ Action on the floor $Mg + F = 490 + 245 = 735$ N

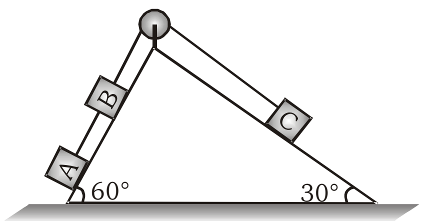
(b) When the block is raised by the man applying force F over the rope (passing over the pulley) in the downward direction, reaction being equal and opposite to F will act on the floor against the weight of the man.

$\therefore$ Action on the floor $Mg - F = 490 - 245 = 245$ N

since floor yields to a normal force of 700 N, mode (b) should be adopted by the man to lift the block.

Illustration 17.

In the adjacent figure, masses of A, B and C are 1 kg, 3 kg and 2 kg respectively.



Find (a) the acceleration of the system and

(b) the tensions in the strings (Neglect friction). ($g = 10$ m/s^2)

Solution

(a) In this case net pulling force

$= m_A g \sin 60° + m_B g \sin 60° - m_C g \sin 30° = (m_A + m_B) g \sin 60° - m_C g \sin 30°$

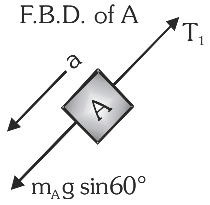
$= (1 + 3) \times 10 \times \frac{\sqrt{3}}{2} - 2 \times 10 \times \frac{1}{2} = 20\sqrt{3} - 10 = 20 \times 1.732 - 10$

$= 24.64$ N

Total mass being pulled $= 1 + 3 + 2 = 6$ kg

$\therefore$ Acceleration of the system $a = \frac{24.64}{6} = 4.1 \text{ m/s}^2$

F.B.D. of A



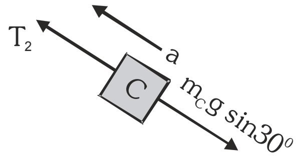
(b) For the tension in the string between A and B.

$m_A g \sin 60° - T_1 = (m_A)(a)$

$\therefore$ $T_1 = m_A g \sin 60° - m_A a = m_A (g \sin 60° - a)$

$\therefore$ $T_1 = (1)\left(10 \times \frac{\sqrt{3}}{2} - 4.1\right) = 4.56$ N

F.B.D. of C



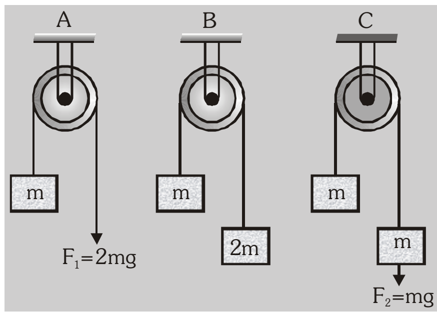
For the tension in the string between B and C.

$T_2 - m_C g \sin 30° = m_C a$

$\therefore$ $T_2 = m_C (a + g \sin 30°) = 2\left[4.1 + 10\left(\frac{1}{2}\right)\right] = 18.2$ N

Illustration 18.

In the figure blocks A, B and C have accelerations a_1, a_2 and a_3 respectively. F_1 and F_2 are external forces of magnitudes 2mg and mg respectively. Find the value of a_1, a_2 and a_3.



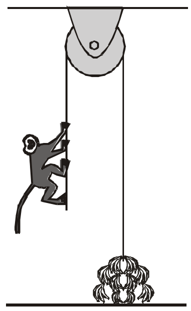
Solution

$$a_1 = \frac{2mg - mg}{m} = g \quad ; \quad a_2 = \frac{2m - m}{2m + m} g = \frac{g}{3}$$

$$a_3 = \frac{mg + mg - mg}{2m} = \frac{g}{2}$$

Illustration 19.

A 12 kg monkey climbs a light rope as shown in fig. The rope passes over a pulley and is attached to a 16 kg bunch of bananas. Mass and friction in the pulley are negligible so that the effect of pulley is only to reverse the direction of force of the rope. What maximum acceleration can the monkey have without lifting the bananas? (Take $g = 10 \text{ m/s}^2$)



Solution

For Monkey

$T - 120 = 12 \times a$ ....(i)

For Bananas

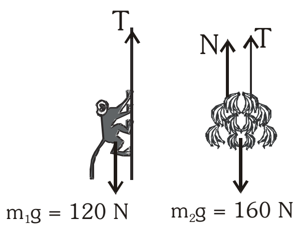
$160 - T = N$

Condition for just loosing the contact is $N = 0$

$160 - T = 0 \quad \Rightarrow \quad T = 160$ ....(ii)

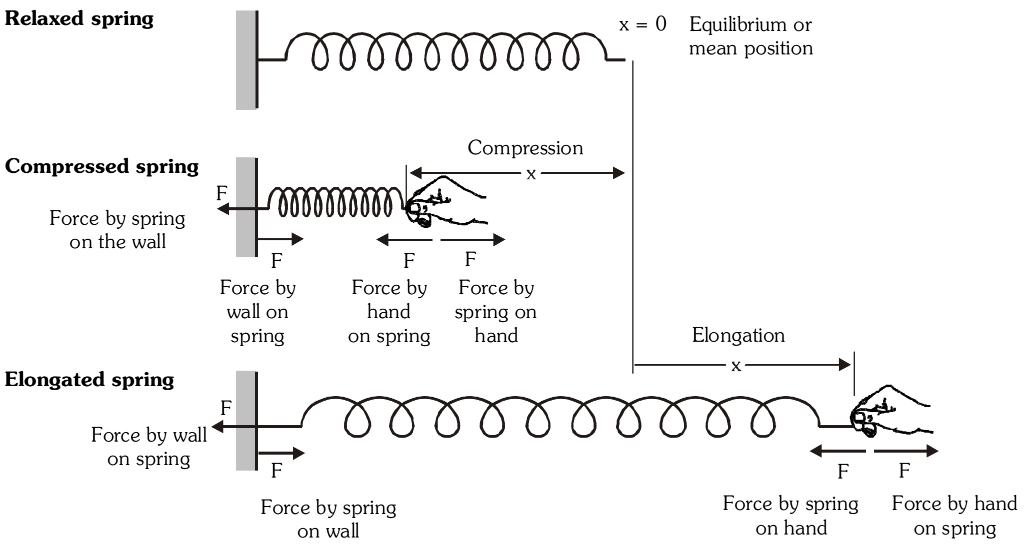
from equation (i) & (ii)

$160 - 120 = 12 \times a \quad \Rightarrow \quad a = 3.33 \text{ m/s}^2$



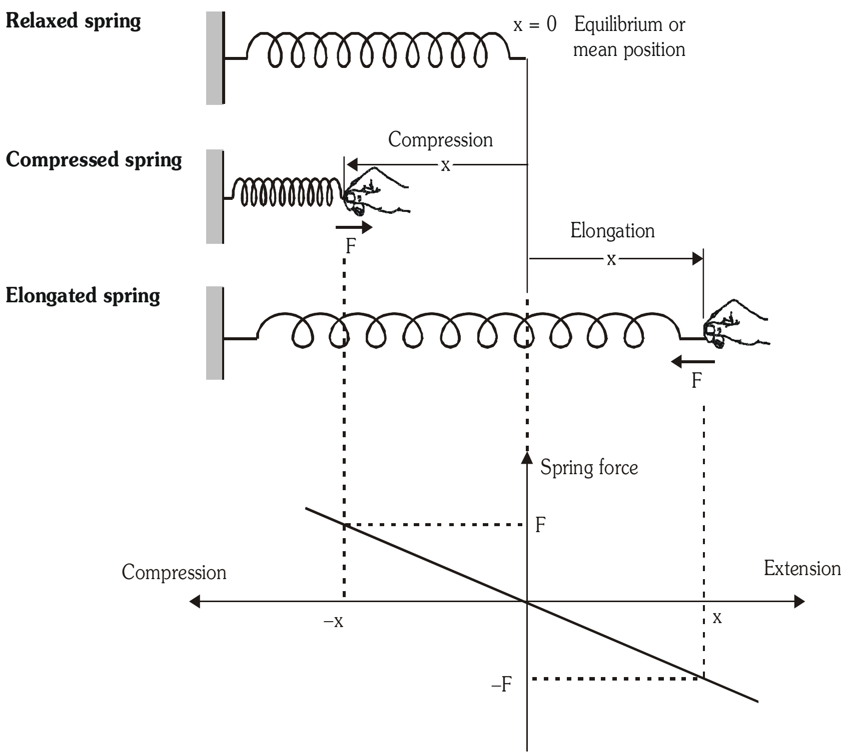
14. SPRING FORCE :

When no force acts on a spring, it is in relaxed condition i.e. neither compressed nor elongated. Consider a spring attached to a fixed support at one of its ends and the other end being free. If we neglect gravity, it remains in a relaxed state. When it is pushed by a force F, it is compressed and displacement x of its free end is called compression. When the spring is pulled by a force F, it is elongated and displacement x of its free end is called elongation. Various forces developed in these situations are shown in the following figure. The force applied by the spring on the wall and the force applied by the wall on the spring form a Newton's third law action-reaction pair. Similarly, force by hand on the spring and force by the spring on the hand form another Newton's third law action-reaction pair.



Hooke's Law:

How spring force varies with deformation in length x of the spring is also shown in the following figure.



The force F varies linearly with x and acts in a direction opposite to x. Therefore, it is expressed by the following equation

$$F = -kx$$

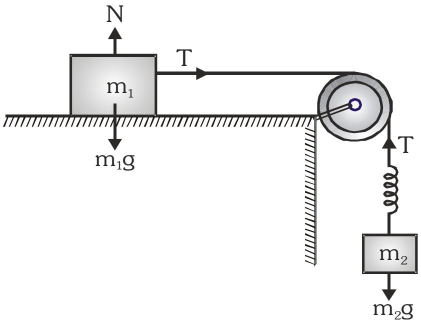
Here, the minus (–) sign represents the fact that force F is always opposite to x.

The constant of proportionality k is known as force constant of the spring or simply as spring constant. The modulus of slope of the graph equals the spring constant.

SI unit of spring constant is newton per meter or (N/m).

Dimensions of spring constant are $[MT^{-2}]$.

For a pulley - spring system (at steady state) :-



Acceleration $a = \dfrac{m_2 g}{m_1 + m_2}$

tension $T = \dfrac{m_1 m_2}{(m_1 + m_2)} g$

If x is the extension in the spring,

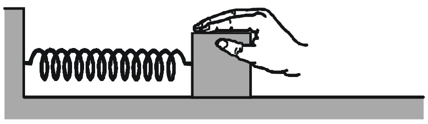
then $T = kx$

$$x = \frac{T}{k} = \frac{m_1 m_2 g}{k(m_1 + m_2)}$$

Illustrations

Illustration 20.

Consider a spring attached to a fixed support at one of its ends and to a box at other end, which rest on a smooth floor as shown in the figure. Denote mass of the box by m, force constant of the spring by k and acceleration due to gravity by g.



The box is pushed horizontally displacing it by a distance x towards the fixed support and held at rest.

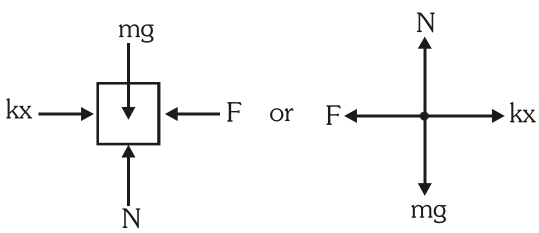
(a) Draw the free body diagram of the box.

(b) Find the force exerted by the hand on the box.

(c) Write all the action-reaction pairs corresponding to Newton's III[rd] law.

Solution

(a) F is push by hand.



(b) Since the block is in equilibrium $\Sigma F_x = 0 \Rightarrow F = kx$

(c) (i) Force on box by hand and force on hand by box.

(ii) Force on box by spring and force on spring by box.

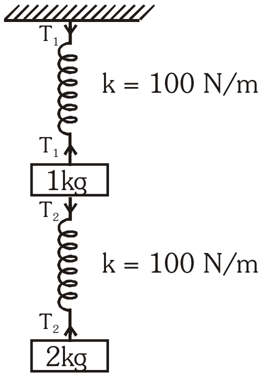
(iii) Normal reaction by box on floor and normal reaction by floor on box.

(iv) Weight of the box and the gravitational force by which box pulls the earth.

(v) Force by spring on support and force by support on spring.

Illustration 21.

Find extension in both the springs



Solution

From figure (a)

$T_2 - 20 = 0 \Rightarrow T_2 = 20$ N ......(1)

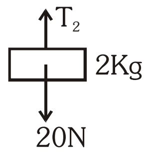


Figure (a)

From figure (b)

$T_1 = T_2 + 10$ ......(2)

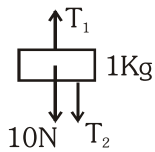


Figure (b)

From equation (1) & (2)

$T_1 = 20 + 10 = 30$ N

For I[st] Spring

$T_1 = kx_1 \quad \Rightarrow 30 = 100 \times x_1 \;\Rightarrow x_1 = 0.3$ m

For 2[nd] Spring

$T_2 = kx_2 \quad \Rightarrow 20 = 100 \times x_2 \;\Rightarrow x_2 = 0.2$ m

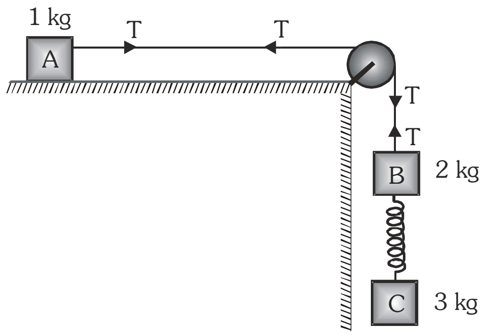
Illustration 22.

In the system shown in figure all surfaces are smooth, string is massless and inextensible. (in steady state) Find the

(a) acceleration of the system

(b) tension in the string and

(c) extension in the spring if force constant of spring is k = 50 N/m (Take g=10 m/s^2)



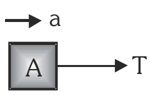
Solution

(a) $3g - kx = 3a$ ..... (1)

$2g + kx - T = 2a$ ..... (2)

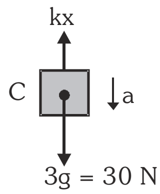
$T = a$ ..... (3)

$\therefore$ Acceleration of the system is $a = \dfrac{50}{6}$ m/s^2

(b) 

Free body diagram of 1 kg block gives $T = ma = (1)\left(\dfrac{50}{6}\right)N = \dfrac{50}{6}N$

(c) Free body diagram of 3 kg block gives

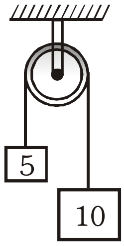


$30 - kx = ma$ but $ma = 3 \times \dfrac{50}{6} = 25$ N

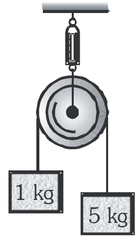
$x = \dfrac{30-25}{k} = \dfrac{5}{50} = 0.1$ m $= 10$ cm

BEGINNER'S BOX-4

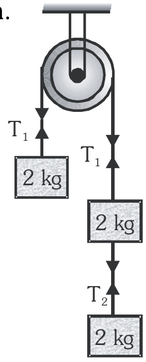
1. The respective masses of the blocks are shown in the diagram in appropriate units. Find acceleration of system, tension in the string and thrust on the pulley (in terms of g).



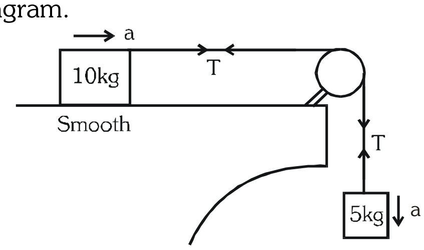
2. Find the reading of the spring balance
Note : Spring balance reads thrust on the pulley which is calibrated in kg-wt.



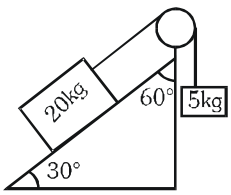
3. Calculate T_1 and T_2 for the following diagram.



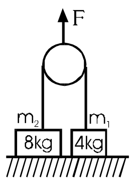
4. Calculate the acceleration of the system, tension in the string and thrust on the pulley in terms of g for the situation shown in following diagram.



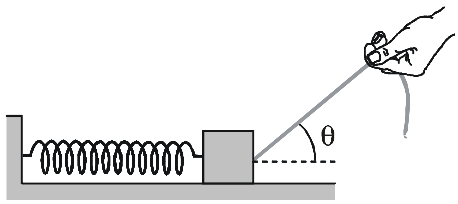
5. Calculate the acceleration of the system and tension in the string for the situation shown in following diagram.



6. Two blocks of masses 8kg and 4 kg respectively are connected by a string as shown. Calculate their accelerations if they are initially at rest on the floor, after a force of 100N is applied on the pulley in the upward direction ($g = 10\ m/s^2$)



7. A block of mass m placed on a smooth floor is connected to a fixed support with the help of a spring of force constant k. It is pulled by a rope as shown in the figure. Tension T of the rope is increased gradually without changing its direction, until the block losses contact the floor. The increase in rope tension T is so gradual that acceleration in the block can be neglected.



(a) Draw its free body diagram, well before the block losses contact with the floor.
(b) What is the necessary tension in the rope so that the block looses contact with the floor?
(c) What is the extension in the spring, when the block looses contact with the floor?

15. FRAME OF REFERENCE

A system with respect to which the position or motion of a particle is described is known as a frame of reference. We can classify frames of reference into two categories :-

(i) Inertial Frame of Reference :

The frame for which law of inertia is applicable is known as inertial frame of reference.

All the frames which are at rest or moving uniformly with respect to an inertial frame, are inertial frame.

(ii) Non-Inertial Frame of Reference :

The frame for which law of inertia is not applicable is known as non-inertial frame of reference.

All the frames which are accelerating or rotating with respect to an inertial frame will be non inertial frames.

16. PSEUDO FORCE

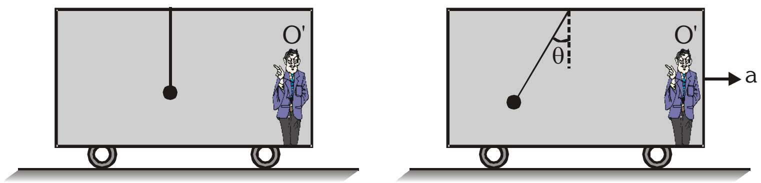
It is a fictitious force or an apparent force or a correction force which is used to explain the motion of objects in non inertial reference frames.

This force always works in the direction opposite to that of acceleration of frame and its magnitude is equal to the product of mass of the body and the acceleration of the non-inertial reference frame.

$$\boxed{\vec{F} = -m\vec{a}}$$

Pseudo force does not follow action-reaction law.

Examples :

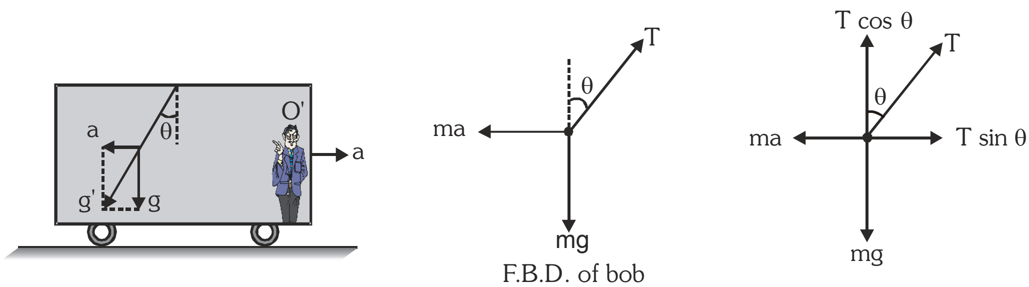


$a = 0$ $\quad\quad$ $a \neq 0$

Illustrations

Illustration 23.

A pendulum of mass m is suspended from the ceiling of a train moving with an acceleration 'a' as shown in figure. Find the angle θ in the equilibrium position. Also calculate tension in the string.



F.B.D. of bob (for an observer in side the train)

Solution

With respect to train, the bob is in equilibrium

$\therefore \quad \Sigma F_y = 0 \Rightarrow T\cos\theta = mg \quad\quad ...(1)$

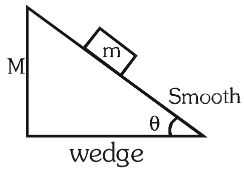
and $\quad \Sigma F_x = 0 \Rightarrow T\sin\theta = ma \quad\quad ...(2)$

Dividing eqns. (2) by (1) $\tan\theta = \frac{a}{g} \Rightarrow \theta = \tan^{-1}\left(\frac{a}{g}\right)$

Squaring and adding eqns. (1) and (2) $T = m\sqrt{a^2 + g^2}$

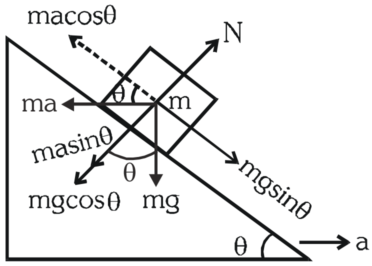
Illustration 24.

What horizontal acceleration should be provided to the wedge so that the block of mass m kept on wedge remains at rest w.r.t. wedge ?



Solution

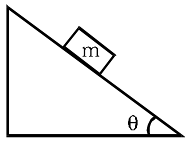
For equilibrium along wedge $\quad ma\cos\theta = mg\sin\theta$



$$\Rightarrow \quad a = g\frac{\sin\theta}{\cos\theta} \quad \Rightarrow \quad \boxed{a = g\tan\theta}$$

Illustration 25.

What horizontal acceleration should be provided to the wedge so that the block of mass m placed on the wedge falls freely?



Solution

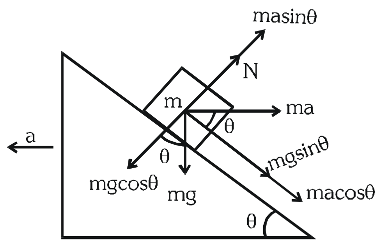
For free fall, normal reaction should be zero

N = 0

For equilibrium perpendicular to the wedge

$0 + ma\sin\theta = mg\cos\theta$

$$\Rightarrow \quad \boxed{a = \frac{g}{\tan\theta}}$$

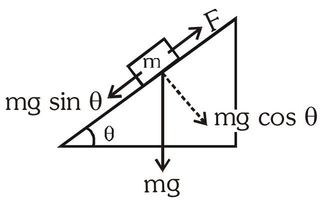


17. MECHANICAL ADVANTAGE :

The ratio of load to effort is called mechanical advantage (M.A.)

Thus, mathematically, $\text{M.A.} = \dfrac{\text{Load}}{\text{effort}}$

e.g : Mechanical advantage of an inclined plane.



$F = mg\sin\theta$

$$\text{M.A. of inclined plane} = \frac{mg}{F} = \frac{mg}{mg\sin\theta} = \frac{1}{\sin\theta} = \text{cosec}\,\theta$$

Illustrations

Illustration 26.

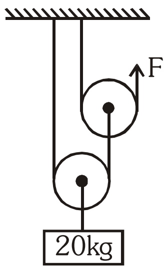
A student is able to lift a bag containing books of 20kg-wt by applying a force of 5kg-wt. Find the mechanical advantage.

Solution

W = 20kg-wt

F = 5kg-wt

$$\text{M.A.} = \frac{20}{5} = 4$$



18. TRANSLATIONAL EQUILIBRIUM

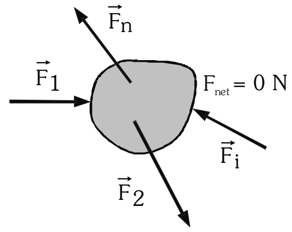
A body in a state of rest or moving with constant velocity is said to be in translational equilibrium. Thus if a body is in translational equilibrium in a certain inertial frame of reference, it must have no linear acceleration. When it is at rest, it is in *static equilibrium*, whereas if it is moving with constant velocity it is in *dynamic equilibrium*.

Conditions for translational equilibrium

For a body to be in translational equilibrium, no net force must act on it i.e. vector sum of all the forces acting on it must be zero.

If several external forces $\vec{F}_1$, $\vec{F}_2$ ..... $\vec{F}_i$ ..... and $\vec{F}_n$ act simultaneously on a body and the body is in translational equilibrium, the resultant of these forces must be zero.

$$\sum \vec{F}_i = \vec{0}$$



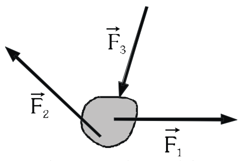
If the forces $\vec{F}_1$, $\vec{F}_2$ ..... $\vec{F}_i$ .....and $\vec{F}_n$ are expressed in Cartesian components, we have :

$$\sum F_{ix} = 0 \qquad \sum F_{iy} = 0 \qquad \sum F_{iz} = 0$$

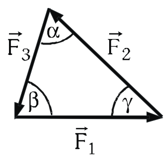
If a body is acted upon by a single external force, it cannot be in equilibrium.

If a body is in equilibrium under the action of only two external forces, the forces must be equal and opposite.

If a body is in equilibrium under the action of three forces, their resultant must be zero. Therefore, according to the triangle law of vector addition they must be coplanar and should form a closed triangle.



$$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = \vec{0} \quad \Rightarrow$$

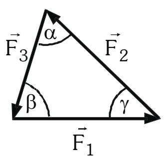


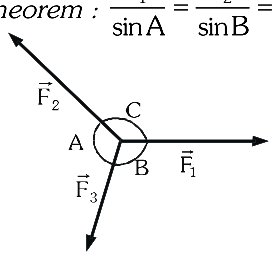
The situation can be analyzed by either graphical or analytical method.

- **Lami's theorem :-**

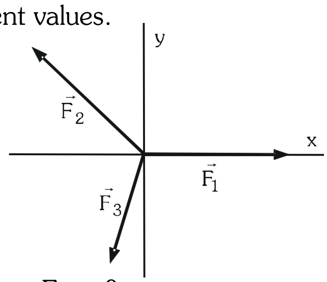
  Graphical method makes use of sine rule or Lami's theorem.

Sine rule : $\dfrac{F_1}{\sin\alpha} = \dfrac{F_2}{\sin\beta} = \dfrac{F_3}{\sin\gamma}$ *Lami's theorem :* $\dfrac{F_1}{\sin A} = \dfrac{F_2}{\sin B} = \dfrac{F_3}{\sin C}$





- Analytical method makes use of Cartesian components. Since the forces involved form a closed triangle, they lie in a plane and a two-dimensional Cartesian frame can be used to resolve the forces. As far as possible orientation of the x-y frame is selected in such a manner that angles made by different forces with the axes should have convenient values.



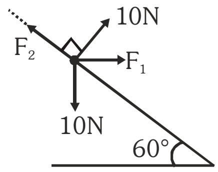
$$\sum F_x = 0 \Rightarrow F_{1x} + F_{2x} + F_{3x} = 0$$

$$\sum F_y = 0 \Rightarrow F_{1y} + F_{2y} + F_{3y} = 0$$

Problems involving more than three forces should be analyzed by analytical method. However, in some situations, there may be some parallel or anti-parallel forces and they should be combined first to minimize the number of forces. This may sometimes reduce a system involving more than three forces to a three-force system.

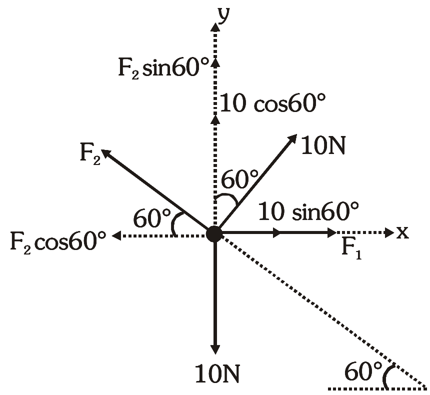
Illustration 27.

In the given figure if all the forces are in equilibrium then calculate F_1 and F_2.



Solution

Resolve the forces along x-direction & y-direction



In x-direction

$\Sigma F_x = 0$ (for equilibrium)

$F_1 + 10 \sin 60° = F_2 \cos 60°$

$\Rightarrow \quad F_1 + 10\left(\frac{\sqrt{3}}{2}\right) = F_2\left(\frac{1}{2}\right)$

$\Rightarrow \quad 2F_1 - F_2 = -10\sqrt{3}$ ..... (i)

In y-direction

$\Sigma F_y = 0$

$F_2 \sin 60° + 10 \cos 60° = 10$

$\Rightarrow \quad F_2\left(\frac{\sqrt{3}}{2}\right) + 10\left(\frac{1}{2}\right) = 10 \Rightarrow F_2(\sqrt{3}) + 10 = 20$

$\Rightarrow \quad F_2 = \left(\frac{10}{\sqrt{3}} N\right)$

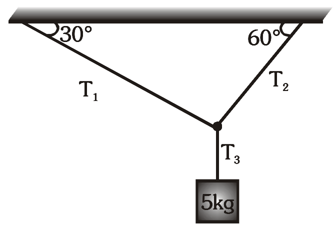
Now from equation (i)

$2F_1 - F_2 = -10\sqrt{3} \quad \Rightarrow \quad 2F_1 - \frac{10}{\sqrt{3}} = -10\sqrt{3}$

$\Rightarrow \quad 2\sqrt{3}F_1 - 10 = -30 \quad \Rightarrow \quad 2\sqrt{3}F_1 = -20 \quad \Rightarrow \quad \boxed{F_1 = \frac{-10}{\sqrt{3}} N}$

Illustration 28.

Calculate the tensions T_1, T_2 and T_3 in the massless strings shown in figure ($g = 10\ m/s^2$)



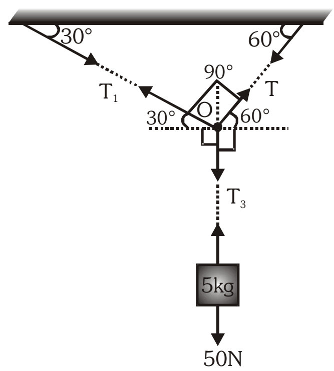
Solution

Considering the adjoining figure

T_3 = wt. of the 5 kg block (mg)

$T_3 = 5 \times 10 = 50$ N

Now applying Lami's theorem at point O.



$$\frac{T_1}{\sin(90° + 60°)} = \frac{T_2}{\sin(90° + 30°)} = \frac{T_3}{\sin(180° - 60° - 30°)}$$

$$\Rightarrow \quad \frac{T_1}{\cos 60°} = \frac{T_2}{\cos 30°} = \frac{50}{\sin 90°}$$

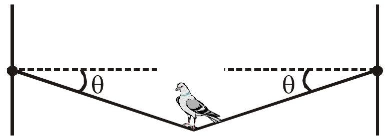
$$T_1 = 50\frac{\cos 60°}{\sin 90°} = 25 \text{ N and } T_2 = 50\frac{\cos 30°}{\sin 90°} = 25\sqrt{3}\text{N}$$

Illustration 29.

A bird of mass m perches at the middle of a stretched string

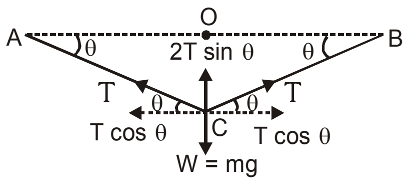
Show that the tension in the string is given by $T = \dfrac{mg}{2\sin\theta}$.

Assume that each half of the string is straight.



Solution

Initial position of string is = AOB. Final position of string is = ACB Let θ be the angle made by the string with the horizontal, which is very small.



Resolving tension T of string in horizontal and vertical directions, we note that the horizontal components cancel while vertical components add and balance the weight. For equilibrium

$$2\,T\sin\theta = W = mg$$

$$\Rightarrow T = \frac{mg}{2\sin\theta}$$

Illustration 30.

(a) A box of weight $10\sqrt{3}$ N is held in equilibrium with the help of two strings OA and OB as shown in figure-I. The string OA is horizontal. Find the tensions in both the strings.

Fig. I

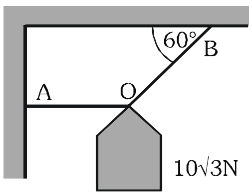
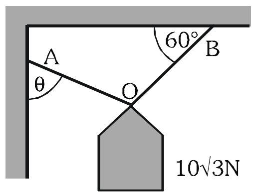


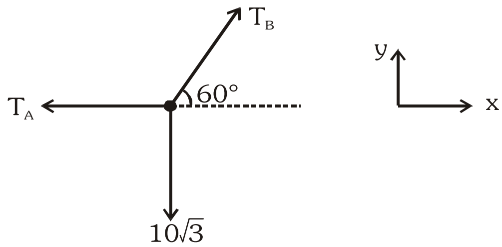
Fig. II



(b) If you can change the location of point A on the wall and hence the orientation of the string OA without altering the orientation of the string OB as shown in figure-II. What angle should the string OA make with the wall so that a minimum tension is developed in it?

Solution

(a) FBD of box



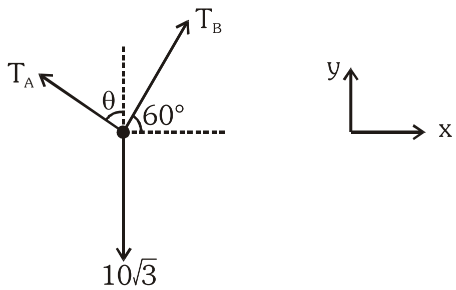
$\Sigma F_x = 0 \Rightarrow T_B \cos 60° - T_A = 0$ ....(i)

$\Sigma F_y = 0 \Rightarrow T_B \sin 60° - 10\sqrt{3} = 0$ ...(ii)

Solving equations (i) and (ii)

We have, T_A = 10 N and T_B = 20 N

(b) FBD of box



$\Sigma F_x = 0 \Rightarrow T_B \cos 60° - T_A \sin\theta = 0$ ...(i)

$\Sigma F_y = 0 \Rightarrow T_A \cos\theta + T_B \sin 60° - 10\sqrt{3} = 0$ ....(ii)

From equation (i) and (ii)

We have $T_A = \dfrac{10\sqrt{3}}{\sqrt{3}\sin\theta + \cos\theta}$

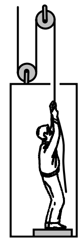
T_A is minimum when $(\sqrt{3}\sin\theta + \cos\theta)$ is maximum.

Now, $(\sqrt{3}\sin\theta + \cos\theta)_{max} = \sqrt{(\sqrt{3})^2 + (1)^2} = 2$

Therefore $(T_A)_{min} = \dfrac{10\sqrt{3}}{2} N = 5\sqrt{3}$ N

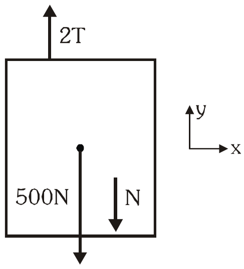
Illustration 31.

A 70 kg man standing on a weighing machine in a 50 kg lift pulls on the rope, which supports the lift as shown in the figure. Find the force with which the man should pull the rope to keep the lift stationary. Also, find the weight of the man as shown by the weighing machine.



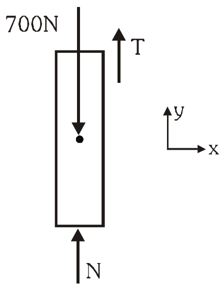
Solution

Magnitude of tension everywhere in the string is same. For equilibrium of the lift.



$\sum F_y = 0 \quad \Rightarrow \quad 500 + N = 2T \qquad ...(i)$

To analyse the equilibrium of the man let us assume him as a block



$\sum F_y = 0 \quad \Rightarrow \quad N + T = 700 \qquad ...(ii)$

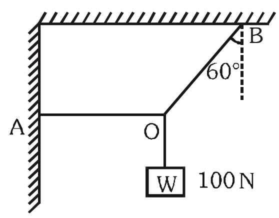
From equations (i) & (ii), we have T = 400 N and N = 300 N

Here, T is the pull of mass and N is the reading of the weighing machine.

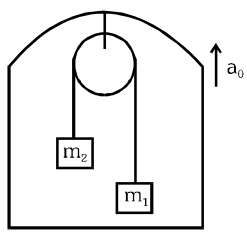
BEGINNER'S BOX-5

1. A block of weight 100 N is suspended (as shown) with the help of three strings.

Find the tension in each of the three strings.



2. Determine the acceleration of the masses w.r.t. lift and tension in the string if the whole system is moving vertically upwards with uniform acceleration a_0. ($m_1 > m_2$)



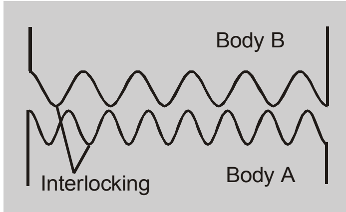
19. FRICTION

19.1 Introduction

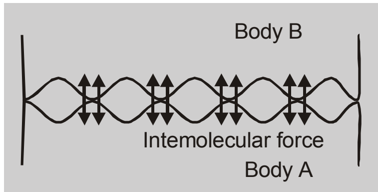
It is that component of total contact force which acts parallel to the contact surface. The friction force always opposes the relative slipping or tendency of relative slipping between the two contact surfaces.

19.2 Cause of Sliding Friction

Old View : When two bodies are in contact with each other, the irregularities in the surface of one body get interlocked with the irregularites in the surface of the other. This inter locking opposes the tendency of relative motion.

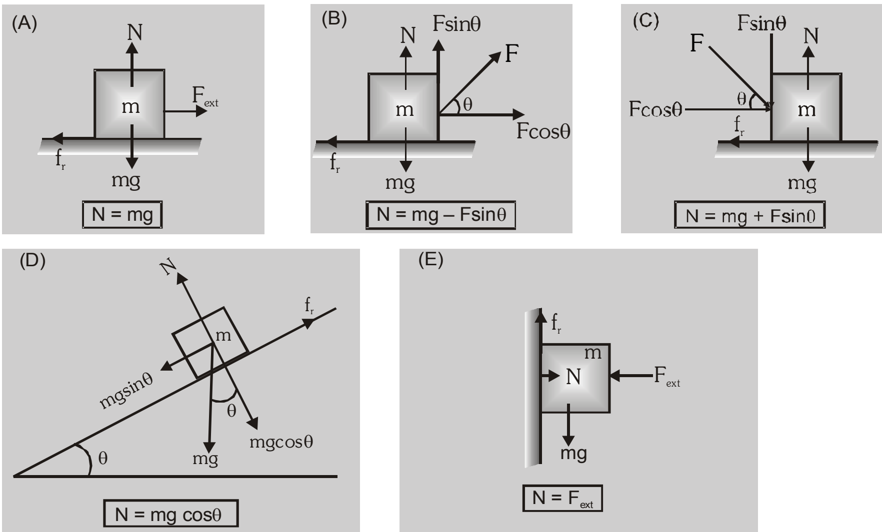


Modern View : Friction arises on account of strong inter atomic or inter molecular forces of attraction between the two surfaces at the point of actual contact.



Friction depends on the following factors :

1. Friction force depends only on the area covered by contact particles of contact surfaces (actual contact area) it does not depend on the area covered by the body (apparent contact area)
2. Except static friction (f_s), friction force depends on normal reaction (N) $f \propto N$



20. TYPES OF FRICTION

Before we proceed further into the details of frictional phenomena, it is advisable to become familiar with different types of frictional forces. All types of frictional phenomenon can be categorized into dry friction, fluid friction, and internal friction.

Dry Friction

It exists when two solid un-lubricated surfaces are in contact under the condition of sliding or tendency of sliding. It is also known as Coulomb friction.

Fluid Friction

Fluid friction is developed when adjacent layers of a fluid move at different velocities and gives rise to a phenomena, which we call viscosity of the fluid. Resistance offered to the motion of a solid body in a fluid also comes in this category and is commonly known as viscous drag. We will study this kind of friction in fluid mechanics.

Internal Friction

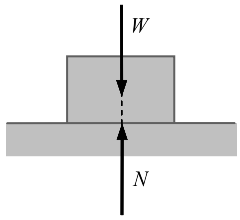
When solid materials are subjected to deformation, internal resistive forces are developed because of relative movement of different parts of the solid. These internal resistive forces constitute a system which is defined as internal friction. They always cause loss of energy.

Frictional forces exist everywhere in nature and result in loss of energy that is primarily dissipated in the form of heat. Wear and tear of moving bodies is another unwanted result of friction. Therefore, sometimes, we try to reduce their effects – such as in bearings of all types, between piston and the inner walls of the cylinder of an internal combustion engine, flow of fluid in pipes, and aircraft and missile propulsion through air. Though these examples create a negative picture of frictional forces, yet there are other situations where frictional forces become essential and we try to maximize its effect. It is the friction between our feet and the ground, which enables us to walk and run. Both the acceleration and braking of wheeled vehicles depend on friction.

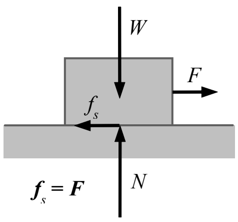
Types of Dry Friction

In mechanics of non-deformable bodies, we are always concerned with the dry friction. Therefore, we often drop the word "dry" and simply call it friction.

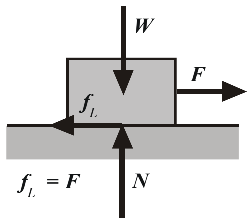
To understand the nature of friction let us consider a box of weight W placed on a rough horizontal surface. The forces acting on the box are its weight and reaction from the horizontal surface. They are shown in the figure. The weight does not have any horizontal component, so the reaction of the horizontal surface on the box is normal to the surface. It is represented by N in the figure. The box is in equilibrium therefore both W and N are equal in magnitude, opposite in direction, and collinear.



Now suppose the box is being pulled by a gradually increasing horizontal force F to slide the box. Initially when the force F is small enough, the box does not slide. This can only be explained if we assume a frictional force, which is equal in magnitude and opposite in direction to the applied force F acts on the box. The force F produces a tendency of relative sliding in the box and the friction force is opposing this tendency of relative sliding. The frictional force developed before relative sliding initiates is defined as static friction. It opposes tendency of relative sliding.

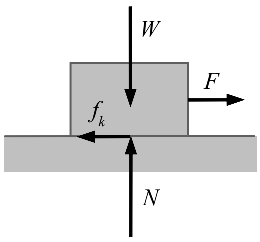


Static Friction



Limiting friction: The maximum Static Friction

As we increase F, the box remains stationary until a value of F is reached when the box starts sliding. Before the box starts sliding, the static friction increases with F and counterbalances F until the static friction reaches its maximum value known as the limiting friction or maximum static friction f_L.



Kinetic friction

When the box starts sliding, a force F is needed to overcome frictional force to maintain its sliding. This frictional force is known as sliding or dynamic or kinetic friction (f_k). It always opposes sliding.

Dry Friction

- **Static Friction**
  Opposes tendency of relative sliding
- **Kinetic/Dynamic/Sliding friction**
  Opposes relative sliding and has a constant characteristic value.

Static Friction

- It is the frictional force which is effective before relative motion begins between two surfaces in contact with each other.
- It's nature is self adjusting (in direction and magnitude upto certain limit)
- Numerical value of static friction is equal to the external force tendency to generate the relative motion of the body.
- Maximum value of static friction is called limiting friction.

21. LAWS OF LIMITING FRICTION

- The magnitude of the force of limiting friction (f_L) between any two bodies in contact is directly proportional to the normal reaction (N) between them

$$f_L \propto N$$

- The direction of the force of limiting friction is always opposite to the direction in which the body is on the verge of moving over the other.
- The force of limiting friction is independent of the apparent contact area, as long as normal reaction between the two bodies in contact remains the same.
- Limiting friction between any two bodies in contact depends on the nature of material of the surfaces in contact and their roughness and smoothness.
- Its value is more than other types of friction force.

22. LAWS OF KINETIC FRICTION

If the body is in relative motion, the friction opposing its relative motion is called dynamic or kinetic friction.

- This is always slightly less than the limiting friction
- It depends on N.
- Its value does not depend on types of motion of body such as accelerated motion, retarded motion or moving with constant velocity because it is a constant friction.
- Its numerical value is $f_k = \mu_k N$, where μ_k = coefficient of kinetic friction.
- **Coefficient of friction :-**

Coefficient of Friction

Static friction coefficient

$$\mu_s = \frac{f_L}{N}$$

Kinetic/Sliding friction coefficient

$$\mu_k = \frac{f_k}{N}$$

The values of μ_s and μ_k depend on the nature of both the surfaces in contact.

The values of μ depend on material of the surfaces in contact.

μ_k and μ_s are dimensionless and unitless.

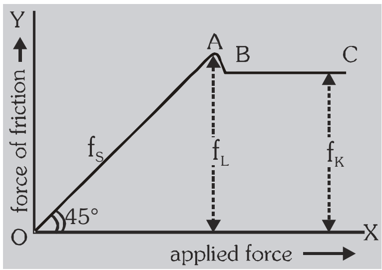
GOLDEN KEY POINTS

- Friction always oppose the tendency of relative motion or the relative motion of contact surface.
- The force of static friction exactly balances the applied force during the stationary state of a body.
- Static friction is a self-adjusting force whereas kinetic friction is not a self adjusting force.
- The frictional force is a contact force parallel to the surfaces in contact and directed so as to oppose the relative motion or attempted relative motion of the surfaces.
- **In exceptional cases μ_s and μ_k can exceed unity**, although their commonly used values are less then 1 in numericals.
- When two highly polished surfaces are pressed hard, then a situation, similar to welding, occurs. It is called **cold welding.**
- When two copper plates are highly polished and placed in contact with each other, then, the force of friction increases instead of decreasing. This arises due to the fact that for two highly polished surfaces in contact, the number of molecules coming in contact increases and as a result the cohesive/adhesive forces increases. This in turn, increases the force of friction.

22.1 Graph Between Applied Force and Force of Friction

The part OA of the curve represents static friction, (f_s) which goes on increasing, with the applied force. At A, the static friction is maximum. This represents the limiting friction. Beyond A, the force of friction is seen to decrease slightly. The portion BC of the curve, therfore, represents the kinetic friction (f_K).

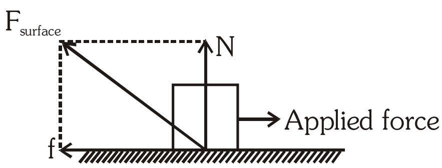
As the portion BC of the curve is parallel to OX, therefore, kinetic friction does not change with the applied force, It remains constant, whatever be the applied force.



22.2 Contact force

Let f be the force of friction and N the normal reaction, then the net contact force by the surface on the object is $F_{surface} = \sqrt{N^2 + f^2}$. Its minimum value (when f = 0) is N and maximum value (when f = μN) is $N\sqrt{1+\mu^2}$

Therefore $N \le F_{surface} \le N\sqrt{1+\mu^2}$

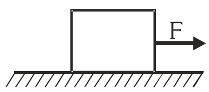


Illustrations

Illustration 32.

A block of mass 1 kg is at rest on a rough horizontal surface having coefficient of static friction 0.2 and kinetic friction 0.15. Find the frictional force if a horizontal force,

(a) F = 1N (b) F = 1.96 N (c) F = 2.5 N is applied on the block



Solution

Maximum force of friction $f_{max} = 0.2 \times 1 \times 9.8 \text{ N} = 1.96 \text{ N}$

(a) For $F_{ext} = 1$ N

$F_{ext} < f_{max}$

So, body is at rest which implies that static friction is present and hence $f_s = F_{ext} = 1$ N

(b) For $F_{ext} = 1.96$ N

$F_{ext} = f_{max} = 1.96$ N

so, $f = 1.96$ N

(c) For $F_{ext} = 2.5$ N

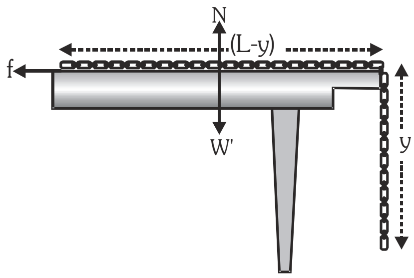
so $F_{ext} > f_{max.}$

Now the body is in motion

$\therefore\ f_{max.} = f_k = \mu_k N = \mu_k\, mg = 0.15 \times 1 \times 9.8 = 1.47$ N

Illustration 33.

Length of a chain is L and coefficient of static friction is μ. Calculate the maximum length of the chain which can hang from the table without sliding.



Solution

Let y be the maximum length of the chain that can be held outside the table without sliding.

Length of chain on the table = (L – y)

Weight of the part of the chain on table $W' = \frac{M}{L}(L-y)g$

Weight of hanging part of the chain $W = \frac{M}{L}yg$

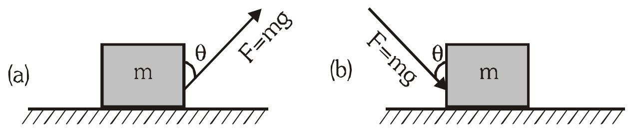
For equilibrium :

limiting force of friction on (L–y) length = weight of hanging part of the chain of y length

$$\mu N = W \Rightarrow \mu W' = W \Rightarrow \mu\frac{M}{L}(L-y)g = \frac{M}{L}yg \Rightarrow \mu L - \mu y = y \Rightarrow y = \frac{\mu L}{1+\mu}$$

Illustration 34.

A block of mass m rests on a rough horizontal surface as shown in figure (a) and (b). Coefficient of friction between the block and surface is μ. A force F = mg act at an angle θ with the vertical side of the block. Find the condition for which the block will move along the surface.

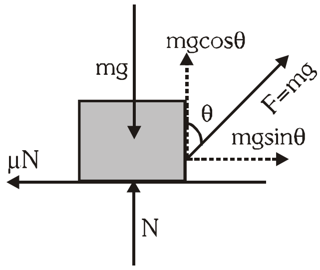


Solution

For (a) : normal reaction N = mg – mg cos θ, limiting frictional force = μN = μ(mg – mg cos θ)

Now, block can be pulled when : Horizontal component of force $\geq$ limiting frictional force

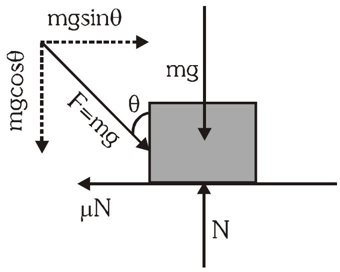
i.e. mg sin $\theta \geq \mu$(mg – mg cos θ)



$$\Rightarrow \quad 2\sin\frac{\theta}{2}\cos\frac{\theta}{2} \geq \mu(1-\cos\theta)$$

$$\Rightarrow \quad 2\sin\frac{\theta}{2}\cos\frac{\theta}{2} \geq 2\mu\sin^2\frac{\theta}{2} \Rightarrow \cot\frac{\theta}{2} \geq \mu$$

For (b) : Normal reaction N = mg + mg cos θ = mg (1 + cos θ)



Hence, block can be pushed along the horizontal surface when horizontal component of force $\geq$ limiting frictional force

i.e. mg sin $\theta \geq \mu$ mg(1 + cos θ)

$$\Rightarrow \quad 2\sin\frac{\theta}{2}\cos\frac{\theta}{2} \geq \mu \times 2\cos^2\frac{\theta}{2} \Rightarrow \tan\frac{\theta}{2} \geq \mu$$

Illustration 35.

A block of mass 2 kg is placed on a plane inclined at an angle of 37° with the horizontal. The coefficient of friction between the block and the surface is 0.7.

(i) What will be the frictional force acting on the block ?

(ii) What is the force applied by inclined plane on block ?

Solution

(i) Normal reaction of the surface N = mg cos 37° = 16 N

$\therefore$ Limiting force of friction $f_L = \mu_s N = \mu_s\, mg \cos 37° = 0.7 \times 2 \times 10 \times \frac{4}{5} = 11.2$ N

$\because$ $mg \sin 37° = 2 \times 10 \times \frac{3}{5} = 12$ N Because $f_L < mg \sin\theta$ so body is in motion

$\therefore$ force of friction $(f_K) = 11.2$ N

(ii) $F = \sqrt{(f_K)^2 + (N)^2} = \sqrt{(11.2)^2 + (16)^2} = \sqrt{125.44 + 256} = \sqrt{381.44} = 19.53$ N

Illustration 36.

A body of mass m rests on a horizontal floor with which it has a coefficient of static friction μ. It is desired to make the body move by applying the minimum possible force F. Find the magnitude of F and the direction in which it has to be applied.

Solution

Let the force F be applied at an angle θ with the horizontal as shown in figure.

For vertical equilibrium,

$N + F \sin\theta = mg$ i.e $N = mg - F \sin\theta$ ......(i)

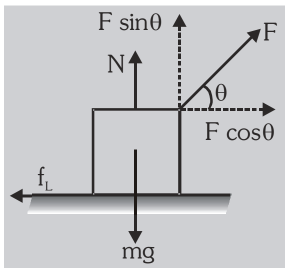
for horizontal motion

$F \cos\theta \geq f_L$ i.e. $F \cos\theta \geq \mu N$ [as $f_L = \mu N$] ......(ii)

substituting expression for N from equation (i) in (ii),

$F \cos\theta \geq \mu(mg - F \sin\theta) \Rightarrow F \geq \dfrac{\mu mg}{(\cos\theta + \mu \sin\theta)}$ ......(iii)

For the force F to be minimum $(\cos\theta + \mu \sin\theta)$ must be maximum,

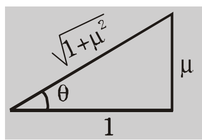


$$\frac{d}{d\theta}(\cos\theta + \mu \sin\theta) = 0$$

or $-\sin\theta + \mu \cos\theta = 0$ i.e., $\tan\theta = \mu$ ..... (iv)

$\therefore$ $\sin\theta = \dfrac{\mu}{\sqrt{1+\mu^2}}$ and $\cos\theta = \dfrac{1}{\sqrt{1+\mu^2}}$

substituting these in equation (iii)



$$F \geq \frac{\mu mg}{\dfrac{1}{\sqrt{1+\mu^2}} + \dfrac{\mu^2}{\sqrt{1+\mu^2}}} \quad \text{i.e.} \quad F \geq \frac{\mu mg}{\sqrt{1+\mu^2}}$$

so that $F_{min} = \dfrac{\mu mg}{\sqrt{1+\mu^2}}$ with $\theta = \tan^{-1}(\mu)$

Note : As $-\sqrt{A^2+B^2} \leq A\sin\theta + B\cos\theta \leq \sqrt{A^2+B^2}$

So $(\cos\theta + \mu\sin\theta)_{max} = \sqrt{1+\mu^2}$ Therefore $F_{min} = \dfrac{\mu mg}{\sqrt{1+\mu^2}}$

BEGINNER'S BOX-6

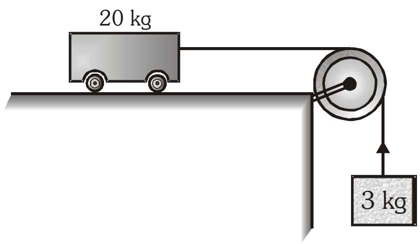
1. A body of mass 5 kg is placed on a rough horizontal surface. If coefficients of static and kinetic friction are 0.5 and 0.4 respectively, then find value of force of friction when external applied horizontal force is (i) 15 N (ii) 25 N and (iii) 35 N.

2. A body of mass 5 kg is placed on a rough horizontal surface. If coefficient of friction is $\frac{1}{\sqrt{3}}$, find what pulling force should act on the body at an angle 30° to the horizontal so that the body just begins to move.

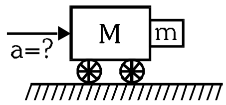
3. A body of mass 0.1 kg is pressed against a wall with a horizontal force 5 N. If coefficient of friction is 0.5 then find force of friction.

4. A body sliding on ice with a velocity of 8 m/s comes to rest after travelling 40 m. Find the coefficient of friction ($g = 9.8\ m/s^2$).

5. What is the acceleration of the block and trolley system shown in fig. if the coefficient of kinetic friction between the trolley and the surface is 0.04? What is the tension in the string? (Take $g = 10\ m/s^2$). Neglect the mass of the string.



6. A cart of mass M has a block of mass m in contact with it as shown in fig. The coefficient of friction between the block and the cart is μ. What should be the minimum acceleration of the cart so that the block of mass m does not fall ?



7. Is it unreasonable to expect the coefficient of friction to exceed unity ?

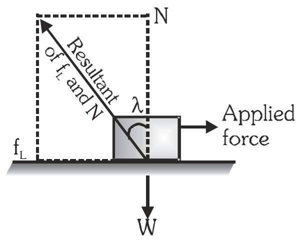
8. It is known that polishing a surface beyond a certain limit increases (rather than decreases) the frictional force. Explain.

9. Why do we slip on a muddy road ?

10. State whether the following statement is true or false :
When a person walks on a rough surface, the frictional force exerted by the surface on the person is opposite to the direction of his motion.

22.3 Angle of friction (λ)

The angle which the resultant of the force of limiting friction f_L and normal reaction N makes with the direction of normal reaction N.



$$\tan\lambda = \frac{f_L}{N} = \mu_s \quad \Rightarrow \quad \boxed{\lambda = \tan^{-1}\mu_s}$$

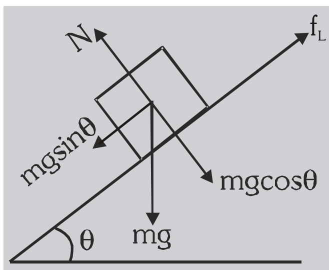
22.4 Angle of Repose or Angle of Sliding

It is defined as the minimum angle of inclination of a plane with the horizontal at which a body placed on it just begins to slide down or equivalently the maximum angle of inclination of plane with the horizontal at which a body placed on it does not slide.

$f_L = mg\sin\theta$ ...(i) and $N = mg\cos\theta$ ...(ii)

Dividing (i) by (ii)

so $\mu_s = \frac{f_L}{N} = \frac{mg\sin\theta}{mg\cos\theta} = \tan\theta \Rightarrow \quad \theta = \tan^{-1}\mu_s$



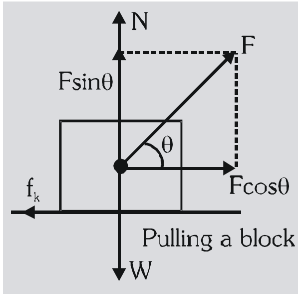
This fact is used for finding the coefficient of static friction in the laboratory.

$$\boxed{\text{Angle of repose}(\theta) = \text{Angle of friction } (\lambda)}$$

22.5 Pulling is Easier Than Pushing

Case of pulling :

Force F is applied to pull a block of weight W.



F can be resolved into two rectangular components : F cosθ and F sinθ.

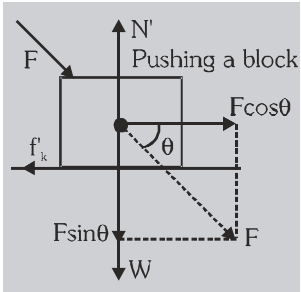
the normal reaction $N = W - F\sin\theta$

Force of kinetic friction $f_k = \mu_k N$

$f_k = \mu_k (W - F\sin\theta)$ ....(i)

Case of pushing :

Force F is applied to push a block



normal reaction $N' = W + F\sin\theta$

Force of kinetic friction $f'_k = \mu_k N'$

or $f'_k = \mu_k (W + F\sin\theta)$ ....(ii)

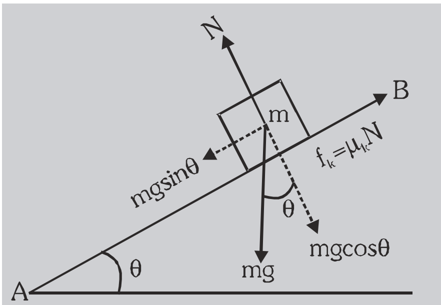
from (i) and (ii) $f'_k > f_k$

The opposing frictional force is more in the case of push. Hence it is easier to pull than to push a body.

22.6 Acceleration of a Body Down a Rough Inclined Plane

If angle of inclination is greater than the angle of repose, then the body accelerates down the incline.

Net force on the body down the inclined plane



$F_{net} = mg\sin\theta - f_r$

applying Newton's second laws of motion

$ma = mg\sin\theta - \mu_k N = mg\sin\theta - \mu_k mg\cos\theta$

$ma = mg[\sin\theta - \mu_k\cos\theta]$

$a = g[\sin\theta - \mu_k\cos\theta]$ hence $a < g$

acceleration of a body down a rough inclined plane is always less than 'g'.

Note :

(i) If we want to prevent the downward slipping of body then minimum upward force required is

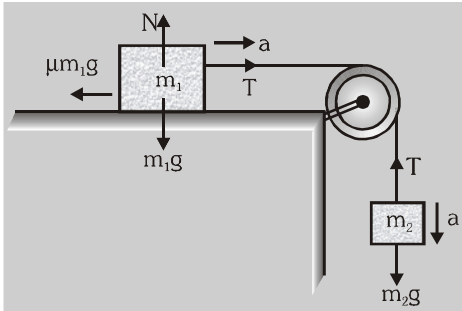
$= mg\sin\theta - \mu_k mg\cos\theta$

(ii) If a body is projected in upward direction along the inclined plane then retardation of body is

$a = g[\sin\theta + \mu_k\cos\theta]$

retardation of a body up a rough inclined plane may be greater than 'g'

22.7 Pulley with friction between block and surface



Case-I : For mass m_1 : $T - \mu m_1 g = m_1 a$

For mass m_2 : $m_2 g - T = m_2 a$

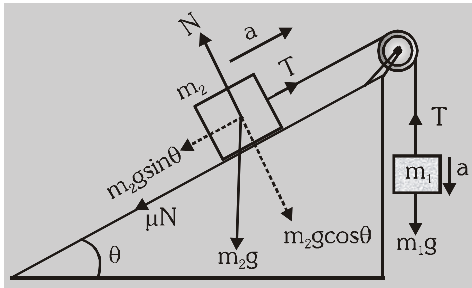
on solving,

Acceleration $a = \dfrac{(m_2 - \mu m_1)g}{(m_1 + m_2)} \Rightarrow T = \dfrac{m_1 m_2 (1+\mu)g}{(m_1 + m_2)}$

Case-II : For mass m_1 : $m_1 g - T = m_1 a$ and $N = m_2 g \cos\theta \Rightarrow \mu N = \mu m_2 g \cos\theta$

For mass m_2 : $T - \mu m_2 g \cos\theta - m_2 g \sin\theta = m_2 a$

on solving,



Acceleration $a = \left[\dfrac{m_1 - m_2(\sin\theta + \mu\cos\theta)}{(m_1 + m_2)}\right] g$

Tension $T = \dfrac{m_1 m_2 (1 + \sin\theta + \mu\cos\theta)g}{(m_1 + m_2)}$

Illustrations

Illustration 37.

A horizontal force of 49 N is just able to move a block of wood weighing 10 kg on a rough horizontal surface. Calculate the coefficient of friction and angle of friction.

Solution :

Here, F = 49 N, N = W = mg = 10 ×9.8N so $\mu = \dfrac{F}{N_s} = \dfrac{49}{10 \times 9.8} = 0.5$

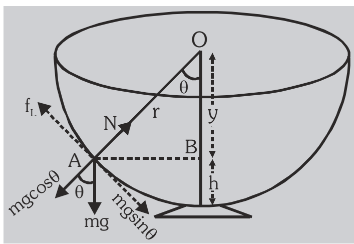
$\Rightarrow \quad \tan\theta = \mu = 0.5 \Rightarrow$ Angle of friction $\theta = \tan^{-1}(0.5)$

Illustration 38.

If the coefficient of friction between an insect and a hemispherical bowl is μ and the radius of the bowl is r, find the maximum height to which the insect can crawl up in the bowl.

Solution

The insect will crawl up the bowl till the component of its weight along the bowl is balanced by limiting frictional force. So, resolving weight perpendicular to the surface of bowl and along the surface of bowl,



$N = mg\cos\theta$ .....(i)

$f_L = mg\sin\theta$ ......(ii)

Dividing (ii) by (i),

$$\tan\theta = \frac{f_L}{N} = \frac{\mu N}{N} = \mu$$

$$\frac{AB}{OB} = \mu \Rightarrow \frac{\sqrt{r^2 - y^2}}{y} = \mu \Rightarrow r^2 - y^2 = \mu^2 y^2 \Rightarrow y^2(1+\mu^2) = r^2 \Rightarrow y = \frac{r}{\sqrt{1+\mu^2}}$$

So $\quad h = r - y = r\left[1 - \dfrac{1}{\sqrt{1+\mu^2}}\right]$

Illustration 39.

A block of mass 2 kg slides down an inclined plane which makes an angle 30° with the horizontal.

The coefficient of friction between the block and the surface is $\frac{\sqrt{3}}{2}$.

(i) What force must be applied to the block so that it moves down the plane without acceleration ?

(ii) What force should be applied to the block so that it moves up without any acceleration ?

Solution

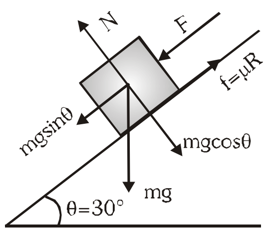
Make a 'free–body' diagram of the block. Take the force of friction opposite to the direction of motion.

(i) Project forces along and perpendicular to the plane. Perpendicular to plane $N = mg\cos\theta$

Along the plane $F + mg\sin\theta - f = 0$

($\because$ there is no acceleration along the plane)

$F + mg\sin\theta - \mu N = 0 \Rightarrow F + mg\sin\theta = \mu\, mg\cos\theta$



$F = mg(\mu\cos\theta - \sin\theta) = 2 \times 9.8\left(\frac{\sqrt{3}}{2}\cos 30° - \sin 30°\right)$

$= 19.6\left(\frac{\sqrt{3}}{2} \times \frac{\sqrt{3}}{2} - \frac{1}{2}\right) = 19.6\left(\frac{3}{4} - \frac{1}{2}\right) = 4.9\text{ N}$

(ii) This time the direction of F is reversed and that of the frictional force is also reversed.

$\therefore N = mg\cos\theta\ ;\ F = mg\sin\theta + f$

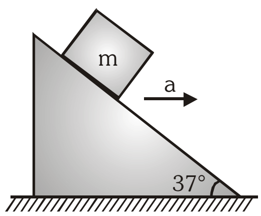
$\Rightarrow F = mg(\mu\cos\theta + \sin\theta) = 19.6\left(\frac{3}{4} + \frac{1}{2}\right) = 24.5\text{ N}$

Illustration 40.

A block of mass 1 kg rests on an incline as shown in figure.

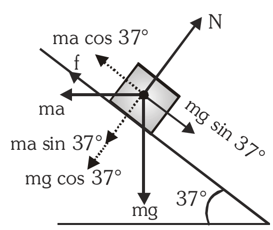
(a) What must be the frictional force between the block and the incline if the block is not to slide along the incline when the incline is accelerating to the right at 3 m/s^2 ?

(b) What is the least value of μ_s which can have for this to happen ?



Solution

$N = m(g\cos 37° + a\sin 37°) = 1(9.8 \times 0.8 + 3 \times 0.6) = 9.64\text{ N}$



$mg\sin 37° = ma\cos 37° + f$

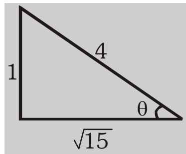
(a) $f = 1(9.8 \times 0.6 - 3 \times 0.8) = 3.48$

(b) $\because f = \mu N \;\therefore\; \mu = \frac{f}{N} = \frac{3.48}{9.64} = 0.36$

Illustration 41.

A body placed on a rough inclined plane just begins to slide. Calculate the coefficient of friction if the gradient (slope) of the plane is 1 in 4.

Solution

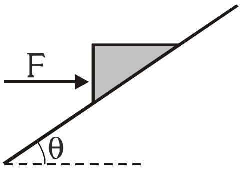


Here $\sin\theta = \frac{1}{4}$

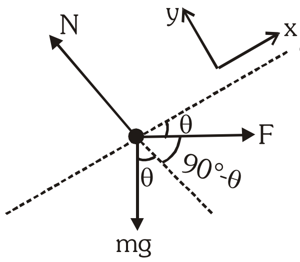
So, $\tan\theta = \frac{1}{\sqrt{15}}$ $\Rightarrow$ $\mu = \tan\theta = \frac{1}{\sqrt{15}} = 0.258$

Illustration 42.

A block rests on a rough inclined plane as shown in fig. A horizontal force F is applied to it (a) Find the force of normal reaction, (b) Can the force of friction be zero, if yes when? and (c) Assuming that friction is not zero find its magnitude and direction of its limiting value.



Solution



(a) $\sum F_y = 0 \rightarrow$ $N = mg\cos\theta + F\sin\theta$

(b) $\sum F_x = 0 \rightarrow$ $F\cos\theta = mg\sin\theta \Rightarrow F = mg\tan\theta$

(c) Limiting friction $f_{sm} = \mu N = \mu\ (mg\cos\theta + F\sin\theta)$;

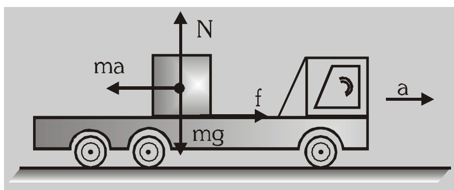
It acts down the plane if body has tendency to slide up

and acts up the plane if body has tendency to slide down.

Illustration 43.

A block of mass 1kg lies on a horizontal surface of a truck; the coefficient of static friction between the block and the surface is 0.6, What is the force of friction on the block, if the acceleration of the truck is 5 m/s^2.

Solution



Fictitious force (pseudo force) on the block opposite to the acceleration of the block

$F = ma = 1 \times 5 = 5N$

While the limiting friction force

$f_L = \mu_s N = \mu_S mg$

$= 0.6 \times 1 \times 9.8 = 5.88$ newton

As applied force F is less than the limiting friction force, the block will remain at rest in the truck and the force of friction will be equal to 5 N and in the direction of acceleration of the truck.

BEGINNER'S BOX-7

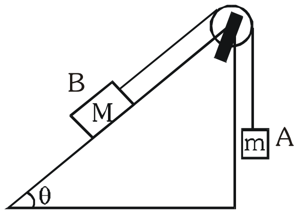
1. A cubical block rests on a plane of $\mu = \frac{1}{\sqrt{3}}$ determine the angle through which the plane be inclined to the horizontal, so that the block just slides down.

2. A body is in limiting equilibrium on a rough inclined plane at angle of 30° with horizontal. Calculate the acceleration with which the body will slide down, when inclination of the plane is changed to 60°.

(Take $g = 10\ m/s^2$)

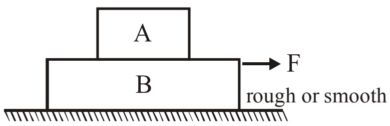
3. A weight W rests on rough horizontal plane. If the angle of friction be θ, then calculate the least horizontal force that will move the body along the plane.

4. Two blocks A and B of masses m and M are connected to the two ends of a string passing over a pulley. B lies on plane inclined at an angle θ with the horizontal and A is hanging freely as shown. The coefficient of static friction between B and the plane is μ_S. Find the minimum and maximum values of m so that the system is at rest.



23. TWO BLOCKS SYSTEM IN FRICTION

Consider two blocks A and B placed one above the other, resting on a horizontal surface. A horizontal force F applied on either blocks, tend to move the system of blocks. Problems involving such situations can conveniently be solving by following mentioned step.



Step 1 : Draw the FBD of the combined block system. If friction appears in the FBD, then take its limiting value (maximum static friction)

If applied force > limiting friction then motion is possible, otherwise not.

If movement occurs then, either the blocks move together or separately depending on the fact that whether frictional forces are able to support the combined motion or not.

Step 2 : Assuming combined motion, find the common acceleration a_C. Draw the FBD of the body on which external force is not applied. Find the frictional force f required to make it move combinedly with the other block. Compare the above calculated force with the limiting value f_L (maximum static friction).

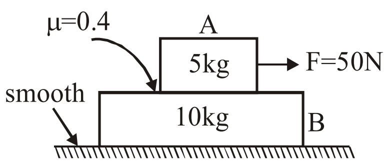
If $f \le f_L$, then both move together with common acceleration a_c. Otherwise, they move separately.

Step 3 : For separate motion, draw the individual FBD's of both blocks with kinetic friction forces acting wherever applicable. Find the individual accelerations of the two blocks using Newton's second law.

Illustrations

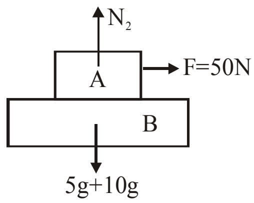
Illustration 44.

Calculate the accelerations of the blocks and the force of friction between them.



Solution

Step 1 : Draw FBD of the combined blocks system.



Obviously, there is an unbalanced force (F=50N) in the horizontal direction.

$\therefore$ Movement occurs.

Step 2: Assuming that the blocks move together with common acceleration

$$a_c = \frac{50}{5+10} = 3.33 \text{ m/s}^2$$

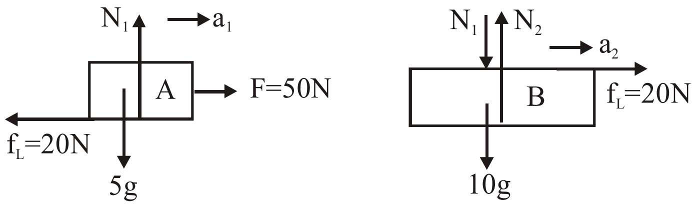
draw the FBD of block B (on which external force is not applied)

Required frictional force $f = m_B a_c = 10 \times 3.33 = 33.3$ N

Now limiting friction (maximum available static friction) $f_L = \mu N_1 = 0.4 \times 5 \times 10 = 20$ N

Obviously, f exceeds f_L. $\therefore$ The two blocks move separately.

Step 3 : Draw the individual FBD's of the two blocks



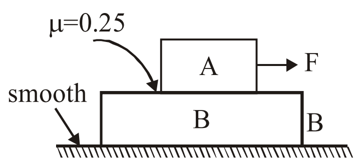
Applying Newton's II law, in the horizontal direction

$$a_1 = \frac{50-20}{5} = 6 \text{ m/s}^2 \text{ and } a_2 = \frac{20}{10} = 2 \text{ m/s}^2$$

Force of friction between the blocks= 20 N

Illustration 45.

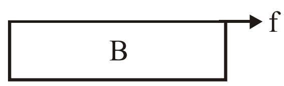
In the figure shown $m_A = 10$ kg, $m_B = 15$ kg. Find the maximum value of F, below which the blocks move together.



Solution

Assuming that both blocks move together, their common acceleration is $a_C = \frac{F}{10+15} = \frac{F}{25}$

FBD of block B (on which no externally applied force acts).



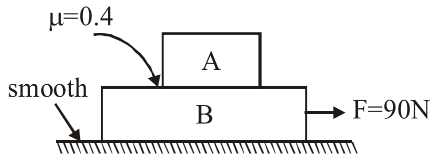
The required friction force f is equal to $f = m_B a_C = \frac{15F}{25} = \frac{3F}{5}$

Now, maximum static friction available is $f_L = \mu N_1 = 0.25(100) = 25$ N (here $N_1 = m_A g = 100$N)

$$\therefore f \le f_L \Rightarrow \frac{3F}{5} \le 25 \Rightarrow F \le \frac{125}{3}\text{N} \Rightarrow F_{max} = \frac{125}{3}\text{N}$$

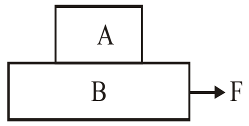
Illustration 46.

For the figure shown, m_A = 10 kg, m_B = 20 kg. F = 90 N. Find the accelerations of the two blocks and the frictional force between them.



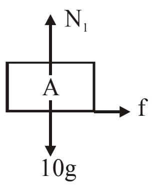
Solution

Step 1 : Draw the FBD of the two block system combindly. Obviously there is an unbalanced horizontal force F = 90 N, so motion begins.



Step2 : Assuming bot the blocks to move together, their common acceleration is

$$a_C = \frac{F}{m_A + m_B} = \frac{90}{10+20} = 3\ m/s^2$$



Draw the FBD of block A (the body on which no externally applied force acts).

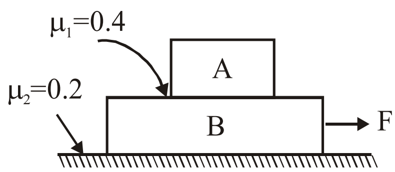
The required frictional force $f = m_A a_C$ = 10×3 = 30 N

Now, maximum static friction (limiting friction) available is $f_L = \mu N_1 = 0.4 \times 10g = 40N$

Obviously, $f < f_L$, so both move together with a common acceleration = 3m/s². The force of friction between them = 30 N.

Illustration 47.

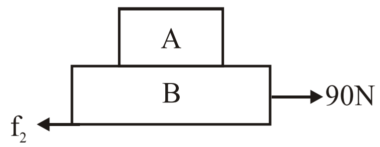
For the figure shown m_A = 10 kg , m_B = 15 kg and F = 90 N. Find the accelerations of the blocks and the frictional forces acting.



Solution

Step1 : Draw the FBD of the combined blocks system.

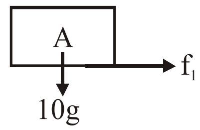
$(f_2)_L = \mu_2 N_2 = 0.2(25g) = 50N \ (\because N_2 = 25g)$



Since 90 N > 50N, net unbalanced forces appear and hence movement begins.

Step 2 : Assuming that both the blocks move together, their combined acceleration is $a_C = \dfrac{90-50}{25} = 1.6\ m/s^2$

Draw the FBD of block A (on which externally applied force does not act).



The force required is $f_1 = m_A a_C = 10 \times 1.6 = 16$ N

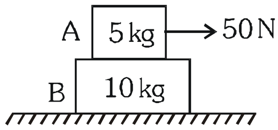
Now, $(f_1)_L = \mu_1 N_1 = 0.4\ (10g) = 40$ N. Clearly, $f_1 < (f_1)_L$

$\therefore$ The frictional force is strong enough to support the combined motion.

$\therefore$ Common acceleration is $a_C = 1.6\ m/s^2$ and $f_1 = 16$ N and $f_2 = 50$ N

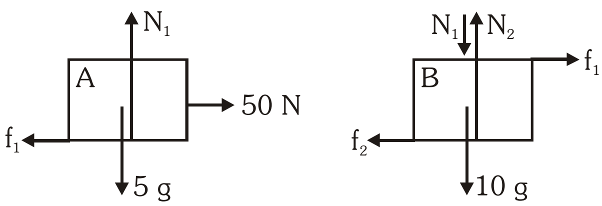
Illustration 48.

Blocks A and B of masses 5 kg and 10 kg are placed as shown in figure. If block A is pulled with 50 N. Find out the accelerations of A and B. If coefficient of friction between A and B is 0.5 and between B and ground is 0.4.



Solution

FBDs of blocks :



Limiting friction between A and B , $f_{1L} = \mu_1 N_1 = 0.5 \times 5g = 24.5$ N

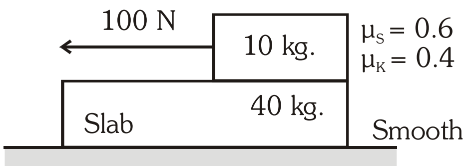
Limiting friction between B and ground $f_{2L} = \mu_2 N_2 = 0.4 \times 15g = 58.8$ N

For block A; $50 - f_1 = 5 \times a \Rightarrow 50 - 24.5 = 5 \times a \Rightarrow a = 5.1\ m/s^2$

For block B accelerating force $f_1 = 24.5$ N is less than the limiting friction $f_2 = 58.8$ N so block B will remain at rest.

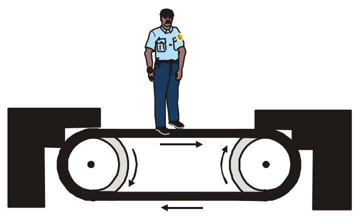
BEGINNER'S BOX-8

1. If 100 N force is applied to the 10 kg block as shown in diagram. What is the acceleration produced for slab and block ?



2. A 3 kg block (A) is placed on a 6 kg block (B) which rests on a table. Coefficient of friction between (A) and (B) is 0.3 and between (B) and table is 0.6. A 30 N horizontal force is applied on the block (B), then calculate the frictional force between the blocks (A) and (B).

3. Figure shows a man standing stationary with respect to a horizontal conveyor belt which is accelerating with $1\ m/s^2$. What is the net force on the man? If the coefficient of static friction between the man's shoes and the belt is 0.2, upto what acceleration of the belt can the man continue to remain stationary relative to the belt? (Mass of the man = 65 kg)



24. METHODS OF REDUCING FRICTION

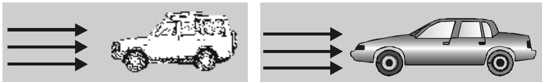
- By polishing the surface. (But extreme polishing increase friction)
- By lubrication.
- By proper selection of materials.

– By avoiding moisture

– By use of alloys

– By streamlining the shape

– By using ball bearings or roller bearings



25. ADVANTAGES AND DISADVANTAGES OF FRICTION

Disadvantages

(i) A significant amount of energy of moving objects is wasted in the form of heat energy to overcome the force of friction.

(ii) Friction restricts the speed of moving vehicles like buses, trains, aeroplanes, rockets etc.

(iii) The efficiency of machines decrease due to the presence of force of friction.

(iv) Friction causes lot of wear and tear in the moving parts of a machine.

(v) Sometimes, machines gets burnt due to the friction between different moving parts.

Advantages

(i) The force of friction helps us to move on the surface of earth. In the absence of friction, we cannot think of walking on the surface. That is why, we fall down while moving on a smooth surface.

(ii) The force of friction between the tip of a pen and the surface of paper helps us to write on the paper. It is not possible to write on a glazed paper as there is no force of friction.

(iii) The force of friction between the tyres of a vehicle and the road aids the vehicle to stop when brakes are applied. In the absence of friction, the vehicle skids off the road after brakes are applied.

(iv) Moving belts remain on the rim of a wheel because of friction.

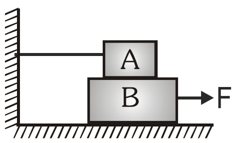
(v) The force of friction between a chalk and a black board helps us to write on the board.

Thus, we observe that inspite of various disadvantages associated with friction, it is very difficult to part with it. Hence, it is commonly said that, friction is a necessary evil.

Illustrations

Illustration 49.

A is a 100 kg block and B is a 200 kg block. As shown in figure, block A is attached to a string tied to a wall. The coefficient of friction between A and B is 0.2 and the coefficient of friction between B and floor is 0.3. Then calculate the minimum force required to move the block B. (take $g = 10\ m/s^2$).



Solution

When B is made to move, by applying a force F, the frictional forces acting on it are f_1 and f_2 with limiting values, $f_1 = (\mu_S)_A m_A g$ and $f_2 = (\mu_S)_B (m_A + m_B)g$

Then minimum value of F should be (such as to overcome these limiting values),

$$F_{min} = f_1 + f_2 = 0.2 \times 100\ g + 0.3 \times 300\ g = 110\ g = 1100\ N$$

ANSWERS

BEGINNER'S BOX-1

1. $4\ cm/s^2$ **2.** 6 s

3. 0.18N, in the direction of motion

4. $a = 2m/s^2$, 37° from 8N

5. 23.89 Ns, 238.9 N

6. 240 **7.** 93.3N

8. 3×10^{-5} Ns, 6×10^{-3} m/s

9. 5 s, 3Ns **10.** 3.18 Ns

11. 5.0×10^{-3} N-s.

BEGINNER'S BOX-2

1. (i) 20M, (ii) 10M, (iii) 5M

2. $1\ ms^{-2}$, (i) 8N (ii) 5 N

3. (i) (P/5m) (ii) P/5 (iii) 2P/5 (iv) 3P/5 (v) 4P/5

BEGINNER'S BOX-3

1. 2 : 5 : 10 **2.** $T = \frac{M(L-Y)}{L} g$

3. 30N, 50N **4.** T = F(x/L)

5. $T = F_1 + (F_2 - F_1)(x/L)$

6. 25 N **7.** $T = \frac{Pm_2}{m_1 + m_2}$

8. 5N, 6N, 7N **9.** 14 N

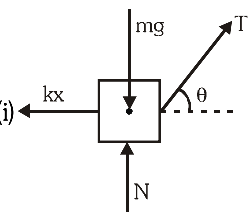
BEGINNER'S BOX-4

1. $\frac{g}{3}, \frac{20g}{3}, \frac{40g}{3}$ **2.** $\frac{10}{3} kg - wt$

3. $T_1 = \frac{8g}{3}, T_2 = \frac{4g}{3}$

4. $\frac{g}{3}, \frac{10g}{3}, \frac{10\sqrt{2}g}{3}$ **5.** $2\ m/s^2$, 60N

6. $a_{4\ kg} = 2.5\ m/s^2$, $a_{8\ kg} = 0$

7. (i) 

, (ii) mg cosec θ, (iii) $\frac{mg \cot\theta}{K}$

BEGINNER'S BOX-5

1. $T_{OB} = 200N$, $T_{OA} = 100\sqrt{3}$ N and $T_{OW} = 100$ N

2. $a = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)(g + a_0)$, $T = \left(\frac{2m_1m_2}{m_1 + m_2}\right)(g + a_0)$

BEGINNER'S BOX-6

1. 15N, 25N and 20N

2. 25N **3.** 1 N **4.** 0.0816

5. $\frac{22}{23}\ m/s^2$, 27.13 N **6.** $\frac{g}{\mu}$

7. For normal plane surfaces the coefficient of friction is less than unity. But when the surfaces are so irregular that sharp minute projections and cavities exist in the surfaces, the coefficient of friction may be greater than one.

8. When a surface is polished beyond a certain limit, the molecules of both surfaces come closer to each other to such an extent that inter molecular forces become appreciable, which exert strong attractive forces on each other. This is called surface adhesion. To overcome these forces, additonal force is required. Hence the frictional force increases.

9. Water on a muddy road provides a thin layer in between our feet and road. This layer breakes the interlocking and decreases the friction.

10. False, when a person walks on a rough surface the man exerts a backward frictional force on the surface. As a result, the surface exerts a forward frictinal force, according to Newton's III law.

BEGINNER'S BOX-7

1. 30°

2. $\frac{10}{\sqrt{3}}\ m/s^2$

3. W tan θ

4. $m_{min} = M(\sin\theta - \mu\cos\theta)$ & $m_{max} = M(\sin\theta + \mu\cos\theta)$

BEGINNER'S BOX-8

1. $0.98\ m/s^2$, $6.08\ m/s^2$

2. Zero **3.** 65 N; $1.96\ m/s^2$

EXERCISE-I (Conceptual Questions)

BASIC QUESTION RELATED TO CONCEPT OF FORCE AND NEWTON'S LAWS OF MOTION

1. A particle is in a straight line motion with uniform velocity. A force is not required :-

(1) To increase the speed

(2) To decrease the speed

(3) To maintain the same speed

(4) To change the direction

2. Essential characteristic of equilibrium is :-

(1) Momentum equals zero

(2) Acceleration equals zero

(3) K.E. equals zero

(4) Velocity equals zero

3. When a constant force is applied to a body, it moves with uniform :-

(1) Acceleration

(2) Velocity

(3) Speed

(4) Momentum

4. A 5 kg mass is accelerated from rest to 60 m/s in 1 s. What force acts on it : -

(1) 5×60 N

(2) $(5/60) \times 981$ N

(3) $60^2 \times 52$ N

(4) $(5/2) \times 60^2 \times 981$N

5. A body of mass 40 g is moving with a constant velocity of 2 cm/s on a horizontal frictionless table. The force on the body (in dynes) is :-

(1) Zero (2) 39200

(3) 160 (4) 80

6. A body of mass 2 kg moving on a horizontal surface with an initial velocity of 4 m/s comes to rest after 2 s. If one wants to keep this body moving on the same surface with a velocity of 4 m/s, the force required is :-

(1) 8 N (2) 4 N

(3) Zero (4) 2 N

7. The distance x covered in time t by a body having initial velocity v_0 and having a constant acceleration a is given by $x = v_0t + \left(\frac{1}{2}\right)at^2$. This result follows from :-

(1) Newton's first law

(2) Newton's second law

(3) Newton's third law

(4) None of these

8. Working of rocket or jet is based on :-

(1) Newton's law (2) Newton's II law

(3) Newton's III law (4) All the three laws

9. When a horse pulls a wagon, the force that causes the horse to move forward is the force

(1) He exerts on the wagon

(2) The wagon exerts on him

(3) The ground exerts on him

(4) He exerts on the ground

10. A man is at rest in the middle of a pond on perfectly smooth ice. He can get himself to the shore by making use of Newton's :-

(1) First law (2) Second law

(3) Third law (4) Law of gravitation

11. A material body A of mass m_1 exerts a force on another material body B of mass m_2. If the acceleration of B be a_2, the magnitude of the acceleration of A is :-

(1) Zero (2) m_2a_2/m_1

(3) m_1a_2/m_2 (4) a_2

12. If the force of gravity suddenly disappears :-

(1) The mass of all bodies will become zero

(2) The weight of all bodies will become zero

(3) Both mass and weight of all bodies will become zero

(4) Neither mass nor weight of all bodies will become zero

13. Two bodies of masses 4 kg and 5 kg are acted upon by the same force. If the acceleration of lighter body is 2 m/s², then the acceleration of the heavier body is :-

(1) 4.2 m/s² (2) 3.6 m/s²

(3) 2.4 m/s² (4) 1.6 m/s²

14. Action and reaction :- (For a given system)

(a) Act on the two different objects

(b) Have opposite directions

(c) Have equal magnitudes

(d) Have zero resultant

(1) a, b, c (2) b, c, d

(3) All of the above (4) None of the above

15. An object with a mass 10 kg moves at a constant velocity of 10 m/s. A constant force then acts for 4 seconds on the object giving it a speed of 2 m/s in opposite direction. The acceleration produced is :-

(1) 3 m/s^2 (2) –3 m/s^2

(3) 0.3 m/s^2 (4) –0.3 m/s^2

16. The velocity acquired by a mass m in travelling a certain distance d starting from rest under the action of a constant force is directly proportional to :-

(1) $\sqrt{m}$ (2) m°

(3) $\frac{1}{\sqrt{m}}$ (4) m

17. Weight is defined as :-

(1) Force of attraction exerted by the earth

(2) Mass of a body

(3) Nature of a body

(4) None of these

18. A ship of mass 3×10^7 kg initially at rest is pulled by a force of 5×10^4 N through a distance of 3m. Neglecting friction, the speed of the ship at this moment is :

(1) 3.0 m/s

(2) 1.5 m/s

(3) 0.1 m/s

(4) 2 m/s

19. In Newton's second Law $\vec{F} = m\vec{a}$ (for constant mass m), $\vec{a}$ is the acceleration of the mass m with respect to

(1) any observer

(2) any inertial observer

(3) an observer at rest only

(4) an observer moving with uniform speed only

20. The ratio of gravitational mass to inertial mass is equal to :

(1) $\frac{1}{2}$ (2) 2

(3) 1 (4) None of these

MOMENTUM, IMPULSE, RATE OF CHANGE OF MOMENTUM AND AVERAGE FORCE RELATED PROBLEMS

21. A balloon of mass M is descending with a constant acceleration g/3. When a mass m is released from the balloon it starts rising with the same acceleration g/3. The value of m is (Assuming that its volume does not change) :-

(1) $\frac{M}{2}$ (2) $\frac{M}{4}$ (3) 4M (4) 2M

22. Gravel is dropped onto a conveyer belt at a rate of 0.5 kg/s. The extra force required in newton to keep the belt moving at 2 m/s is :-

(1) 1 N (2) 2 N

(3) 4 N (4) 0.5 N

23. A block of metal weighing 2 kg is resting on a frictionless plane. It is struck by a jet releasing water at a rate of 1 kg/s with a speed of 5 m/s. The initial acceleration of the block will be :-

(1) 2.5 m/s^2 (2) 5 m/s^2

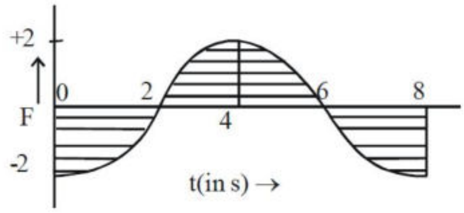
(3) 10 m/s^2 (4) 15 m/s^2

24. A ball weighing 10 g hits a hard surface vertically with a speed of 5 m/s and rebounds with the same speed. The ball remains in contact with the surface for (0.01) s. The average force exerted by the surface on the ball is :-

(1) 100 N (2) 10 N

(3) 1 N (4) 0.1 N

25. Force-time graph for the motion of a body is shown in fig. Change in linear momentum between 0 to 8 s is :-



(1) Zero (2) 4 N-s

(3) 8 N-s (4) None

26. Newton's II law of motion connects :

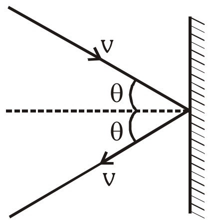
(1) Momentum and acceleration

(2) Change of momentum and velocity

(3) Rate of change of momentum and external force

(4) Rate of change of force and momentum

27. A water jet, whose cross sectional are is 'a' strikes a wall making an angle 'θ' with the normal and rebounds elastically. The velocity of water of density 'd' is v. Force exerted on wall is :-



(1) $2\ av^2d\cos\theta$ (2) $2\ av^2d\sin\theta$

(3) $2\ avd\cos\theta$ (4) $avd\cos\theta$

28. When we kick a stone, we get hurt. Due to which of the following properties of stone does it happens ?

(1) Inertia (2) Velocity

(3) Reaction (4) Momentum

29. A player catches a ball of 200 g moving with a speed of 20 m/s. If the time taken to complete the catch is 0.5 s, the force exerted on the player's hand is :-

(1) 8 N (2) 4 N

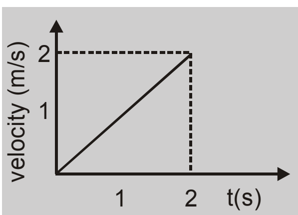
(3) 2 N (4) 0

30. A tennis ball is dropped on the floor from a height of 20 m. It rebounds to a height of 5 m. The ball was in contact with the floor for 0.01 s. What was its average acceleration during the contact ? ($g=10 m/s^2$)

(1) $3000\ m/s^2$ (2) $2000\ m/s^2$

(3) $1000\ m/s^2$ (4) $500\ m/s^2$

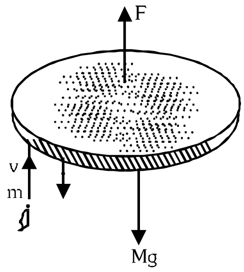
31. For a body of 50 kg mass, the velocity-time graph is shown in figure.The force acting on the body is :



(1) 25 N (2) 50 N

(3) 12.5 N (4) 100 N

32. A disc of mass 1·0 kg is kept floating horizontally in air by firing bullets of mass 0·05 kg each vertically at it, at the rate of 10 per second. If the bullets rebound with the same speed, the speed with which these are fired will be–



(1) 0·098 m/s (2) 0·98 m/s

(3) 9·8 m/s (4) 98·0 m/s

33. A satellite in force free space sweeps stationary interplanetary dust at a rate $(dM/dt) =+ \alpha v$. Here v is the velocity. The acceleration of satellite of mass M is :-

(1) $-\ 2\ \alpha v^2/M$ (2) $-\ 3\ \alpha v^2/M$

(3) $-\ \alpha v^2/M$ (4) $-\ \alpha v^2$

34. If force $F = 500 - 100t$, then impulse as a function of time will be :-

(1) $500t - 50t^2$ (2) $50t - 10$

(3) $50 - t^2$ (4) $100t^2$

35. For a Rocket propulsion velocity of exhaust gases relative to rocket is 2 km/s. If mass of rocket system is 1000 kg, then the rate of fuel consumption for a rocket to rise up with an acceleration $4.9\ m/s^2$ will be :-

(1) 12.25 kg/s (2) 17.5 kg/s

(3) 7.35 kg/s (4) 5.2 kg/s

36. If the force on a rocket moving in force free space with an exhaust velocity of gases 300 m/sec is 210 N, then the rate of combustion of the fuel, is :-

(1) 0.7 kg/s (2) 1.4 kg/s

(3) 2.7 kg/s (4) 10.7 kg/s

37. A rocket of mass 120 kg. is fired in a gravity free space is ejecting gases with velocity 600 m/s at the rate of 1 kg/s. What will be the initial acceleration of the rocket ?

(1) $1\ m/s^2$ (2) $5\ m/s^2$

(3) $10\ m/s^2$ (4) $15\ m/s^2$

38. n bullet strike per second elastically on a wall and rebound. What will be the force exerted on the wall by bullets if mass of each bullet is m :-

(1) mnv (2) 4mnv

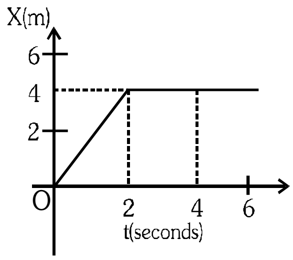
(3) 2mnv (4) $\frac{mnv}{2}$

39. A monkey of mass 20 kg is holding a vertical rope. The rope will not break when a mass of 25 kg is suspended from it but will break if the mass exceeds 25 kg what is the maximum acceleration with which the monkey can climb up along the rope ? ($g = 10\ m/s^2$)

(1) $5\ m/s^2$ (2) $10\ m/s^2$

(3) $25\ m/s^2$ (4) $2.5\ m/s^2$

40. In the figure given below, the position–time graph of a particle of mass 0·1 kg is shown. The impulse at t=2 sec is –



(1) 0·2 kg-m/s

(2) –0·2 kg-m/s

(3) 0·1 kg-m/s

(4) –0·4 kg-m/s

41. A person is standing in an elevator. In which situation he finds his weight less ?

(1) when the elevator moves upward with constant acceleration

(2) when the elevator moves downward with constant acceleration

(3) when the elevator moves upward with uniform velocity

(4) when the elevator moves downward with uniform velocity

42. A force of 10 N acts on a body of mass 20 kg for 10 seconds. The change in its momentum is

(1) 50 kg-m/s (2) 100 kg-m/s

(3) 300 kg-m/s (4) 1000 kg-m/s

43. A rocket of mass 1000 kg is to be projected vertically upwards. The gases are exhausted vertically downwards with velocity 100 m/s with respect to the rocket. What is the minimum rate of burning fuel, so as to just lift the rocket upwards against the gravitational attraction ? (Take $g = 10\ m/s^2$)

(1) 50 kg/s (2) 100 kg/s

(3) 200 kg/s (4) 400 kg/s

44. A 150 g tennis ball coming at a speed of 40 m/s is hit straight back by a bat to speed of 60 m/s. The magnitude of the average force F on the ball, when it is in contact for 5 ms with the bat is :-

(1) 2500 N (2) 3000 N

(3) 3500 N (4) 4000 N

45. Ten one-rupee coins are put on top of each other on a table. Each coin has a mass m. Which of the following statements is not true ?

(1) The force on the 6^{th} coin (counted from the bottom) due to all the coins on its top is equal to 4mg (downwards).

(2) The force on the 6^{th} coin due to the 7^{th} coin is 4mg (downwards)

(3) The reaction of the 6th coin on the 7^{th} coin is 4mg (upwards).

(4) The total force on the 10^{th} coin is 9mg (downwards)

46. A 140 g ball, in horizontal flight with a speed of 39.0 m/s, is struck by a bat. After leaving the bat, the ball travels in the opposite direction with speed $v_2 = 39.0$ m/s. If the impact time Δt for the ball-bat collision is 1.20 ms, what average force acts on the ball ?

(1) 1308 N (2) 1090 N

(3) 9100 N (4) 980 N

FREE BODY DIAGRAM, EQUILIBRIUM OF CONCURRENT FORCES-LAMI'S THEOREM

47. A cork of mass 10 g is floating on water. Net force on the cork is :-

(1) 10 N (2) 10^{-3}N

(3) 10^{-2} N (4) Zero

48. Two persons hold a rope of negligible weight tightly at its ends so that it is horizontal. A 15 kg weight is attached to the rope at the mid point which is now no longer remains horizontal. The minimum tension required to completely straighten the top is

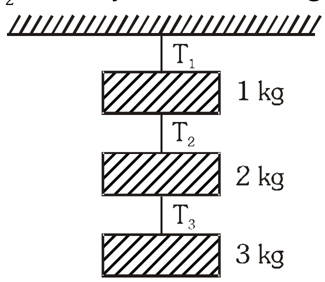
(1) 15 kg (2) 15/2 kg

(3) 5 kg (4) Infinitely large

49. A boy of mass 40 kg is hanging from a horizontal branch of a tree. The tension in his arms is minimum when the angle between the arms is :-

(1) 0° (2) 90° (3) 120° (4) 180°

50. Find the tension T_2 for the system shown in fig.



(1) 1g N

(2) 2g N

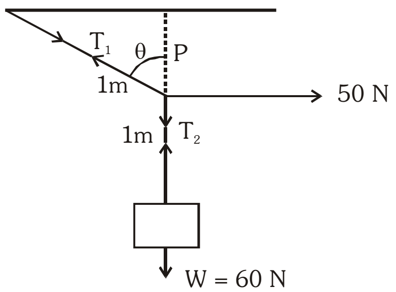
(3) 5g N

(4) 6g N

51. Ten one rupees coins are put on top of each other on a table. Each coin has a mass 'm' kg., then the force on the 7^{th} coin (counted from the bottom) due to all the coins on its top :-

(1) 3 mg (2) 7 mg (3) 2 mg (4) 5 mg

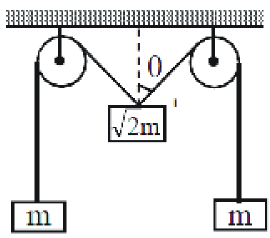
52. A mass of 6 kg is suspended by a rope of length 2 m from a ceiling. A force of 50 N is applied in horizontal direction at the mid point of the rope. What is the angle between the rope and the vertical in equilibrium :-



(1) $\tan^{-1}\left(\frac{4}{5}\right)$ (2) $\tan^{-1}\left(\frac{5}{4}\right)$

(3) $\tan^{-1}\left(\frac{5}{6}\right)$ (4) None

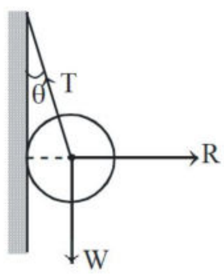
53. The pulleys and strings shown in the fig. are smooth and are of negligible mass. For the system to remain in equilibrium, the angle θ should be



(1) 0° (2) 30°

(3) 45° (4) 60°

54. A metal sphere is hung by a string fixed to a wall. The forces acting on the sphere are shown in fig. Which of the following statements is correct ?



(a) $\vec{R}+\vec{T}+\vec{W}=0$ (b) $T^2 = R^2 + W^2$

(c) $T = R + W$ (d) $R = W \tan\theta$

(1) a, b, c (2) b, c, d

(3) a, b, d (4) a, b, c, d

55. A block of mass 4 kg is suspended through two light spring balances A and B in series. Then A and B will read respectively.

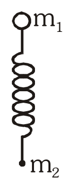
(1) 4 kg and zero kg

(2) zero kg and 4 kg

(3) 4 kg and 4 kg

(4) 2 kg and 2 kg

56. Two masses m_1 and m_2 are joined by a spring as shown. The system is dropped to the ground from a certain height. The spring will be :-



(1) Stretched when $m_2 > m_1$

(2) compressed when $m_2 < m_1$

(3) neither compressed nor stretched only when $m_1 = m_2$

(4) neither compressed nor stretched regardless of the values of m_1 and m_2.

57. A man weighs 80 kg. He stands on a weighing scale in a lift which is moving upwards with a uniform acceleration of $5 m/s^2$. What would be the reading on the scale ? ($g = 10 m/s^2$)

(1) Zero (2) 400 N

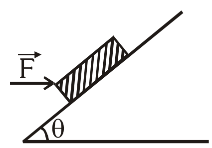
(3) 800 N (4)1200 N

58. A block of mass m is placed on a smooth wedge of inclination θ. The whole system is accelerated horizontally so that the block does not slip on the wedge. The force exerted by the wedge on the block (g is acceleration due to gravity) will be :–

(1) $mg \sin\theta$ (2) mg

(3) $mg/\cos\theta$ (4) $mg \cos\theta$

59. The figure shows a horizontal force $\vec{F}$ acting on a block of mass M on an inclined plane (angle θ). What is the normal reaction on the block ?



(1) $mg\sin\theta + F\cos\theta$ (2) $mg\sin\theta - F\cos\theta$

(3) $mg\cos\theta - F\sin\theta$ (4) $mg\cos\theta + F\sin\theta$

60. A man, of mass 60 kg, is riding in a lift. The weights of the man, when the lift is accelerating upwards and downwards at 2 m/s^2 are respectively :- (Taking g = 10 m/s^2)

(1) 720 N and 480 N

(2) 480 N and 720 N

(3) 600 N and 600 N

(4) none of these

FRAME OF REFERENCE - INTERTIAL OR NON INERTIAL FRAME, PSEUDO FORCE, ACCELERATING LIFT

61. A man is standing at a spring platform. Reading of spring balance is 60 kg-wt. If the man jumps off from the platform, then reading of spring balance :-

(1) First increases then decreases to zero

(2) Decreases

(3) Increases

(4) Remains same

62. A small sphere is suspended by a string from the ceiling of a car. If the car begins to move with a constant acceleration $\frac{g}{2}$, the inclination of the string with the vertical is :-

(1) $\tan^{-1}\left(\frac{1}{2}\right)$ in the direction of motion

(2) $\tan^{-1}\left(\frac{1}{2}\right)$ opposite to the direction of motion

(3) $\tan^{-1}(2)$ in the direction of motion

(4) $\tan^{-1}(2)$ opposite to the direction of motion

63. A boy sitting on the upper berth in the compartment of a train, which is about to stop at a railway station, drops an apple aiming at the open hand of his brother vertically below his hands at a distance of about 2 m. The apple will fall :-

(1) In the hand of his brother

(2) Slightly away from the hands of his brother in the direction of motion of the train

(3) Slightly away from the hands of his brother in the direction opposite to the direction of motion of the train

(4) None of the above

64. The force exerted by a person on the floor of an elevator is more than the weight of the person if the elevator is :-

(a) Going up and slowing down

(b) Going up and speeding up

(c) Going down and slowing down

(d) Going down and speeding up

(1) a, c (2) b, c (3) a, d (4) b, d

65. The ratio of weights of a man in a stationary lift and in a lift accelerating downwards with a uniform acceleration is 3 : 2. The acceleration of the lift is:-

(1) $\frac{g}{3}$ (2) $\frac{g}{2}$ (3) g (4) $\frac{4}{3}g$

66. A frame will be inertial, if it moves with respect to another inertial frame with a constant :-

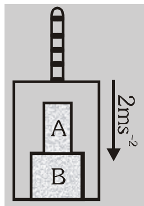
(1) Linear velocity

(2) Angular velocity

(3) Linear acceleration

(4) All of the above

67. The elevator shown in figure is descending, with an acceleration of 2 m/s^2. The mass of the block A is 0.5 kg. The force exerted by the block A on the block B is :



(1) 2 N (2) 4 N

(3) 6 N (4) 8 N

68. A man weighing 100 kg carries a load of 10 kg on his head. He jumps from a tower with the load on his head. What will be the weight of the load as experienced by the man ?

(1) zero

(2) 10 kg

(3) slightly more than 10 kg

(4) 110 kg

69. Drums of oil are carried in a truck. If the truck accelerates at a constant rate, the surface of the oil in the drum will -

(1) Remain unaffected

(2) Rise in the forward direction

(3) Rise in the backward direction

(4) Nothing is certain

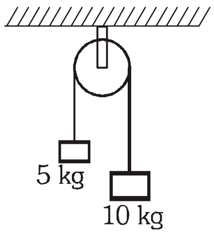
70. A body kept on a smooth inclined plane of inclination 1 in x will remain stationary relative to the inclined plane if the plane is given a horizontal acceleration equal to :-

(1) $\sqrt{x^2-1}g$ (2) $\frac{\sqrt{x^2-1}}{x}g$

(3) $\frac{gx}{\sqrt{x^2-1}}$ (4) $\frac{g}{\sqrt{x^2-1}}$

MOTION OF BODIES IN CONTACT OR CONNECTED BY STRINGS, PULLEY SYSTEM

71. Two blocks of masses 5 kg and 10 kg are connected to a pulley as shown. What will be their acceleration if the pulley is set free ? (g = acceleration due to gravity)



(1) g (2) g/2 (3) g/3 (4) g/4

72. Three solids of masses m_1, m_2 and m_3 are connected with weightless string in succession and are placed on a frictionless table. If the mass m_3 is dragged with a force T. The tension in the string between m_2 and m_3 is :-

(1) $\frac{m_2}{m_1+m_2+m_3}T$ (2) $\frac{m_3}{m_1+m_2+m_3}T$

(3) $\frac{m_1+m_2}{m_1+m_2+m_3}T$ (4) $\frac{m_2+m_3}{m_1+m_2+m_3}T$

73. Two particles of masses m and M (M > m) are connected by a cord that passes over a massless and frictionless pulley. The tension T in the string and the acceleration a of the particles is :-

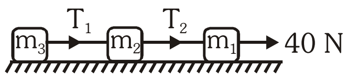
(1) $T=\frac{2mM}{(M-m)}g;\ a=\left(\frac{Mm}{M+m}\right)g$

(2) $T=\frac{2mM}{(M+m)}g; a=\left(\frac{M-m}{M+m}\right)g$

(3) $T=\left(\frac{M-m}{M+m}\right)g;\ a=\left(\frac{2mM}{M+m}\right)g$

(4) $T=\left(\frac{Mm}{M+m}\right)g;\ a=\left(\frac{2mM}{M+m}\right)g$

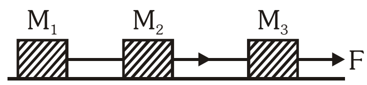
74. Three blocks of masses m_1,m_2 and m_3 are connected by massless strings as shown in the figure on a frictionless table. They are pulled with a force of 40 N. If m_1 = 10 kg, m_2 = 6 kg and m_3 = 4 kg, then tension T_2 will be :-



(1) 10 N (2) 20 N

(3) 32 N (4) 40 N

75. Three masses M_1, M_2 and M_3 are lying on a frictionless table. The masses are connected by massless threads as shown. The mass M_3 is pulled by a constant force F as shown. The tension in the thread between masses M_2 and M_3 is



(1) $\left(\frac{M_1+M_2}{M_1+M_2+M_3}\right)F$

(2) $\left(\frac{M_2+M_3}{M_1+M_2+M_3}\right)F$

(3) $\left(\frac{M_1+M_3}{M_1+M_2+M_3}\right)F$

(4) $\left(\frac{M_1-M_2}{M_1+M_2+M_3}\right)F$

76. Two bodies A and B of masses 10 kg and 15 kg respectively kept on a smooth, horizontal surface are tied to the ends of a light string. If T represents the tension in the string when a horizontal force F = 500 N is appleid to A (as shown in figure 1) and T' be the tension when it is applied to B (figure2), then which of the following is true?

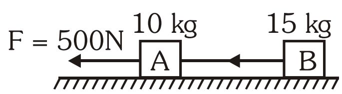


Fig. (1)

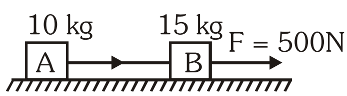


Fig. (2)

(1) T = T' = 500 N

(2) T = T' = 250 N

(3) T = 200 N, T' = 300 N

(4) T = 300 N, T' = 200 N

77. If a parrot starts flying upwards with an acceleration in an air tight cage, then the boy will feel the weight of the cage:

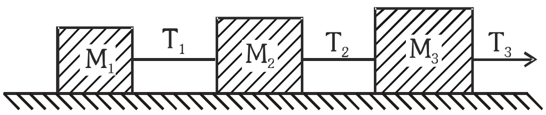
(1) Unchanged (2) Reduced

(3) Increased (4) Nothing can be said

78. Two blocks of masses 2 kg and 1 kg are in contact with each other on a frictionless table. When a horizontal force of 3.0 N is applied to the block of mass 2 kg the value of the force of contact between the two blocks is -

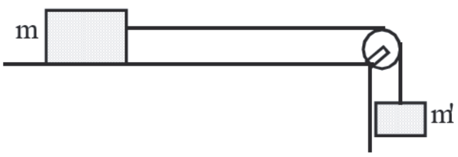
(1) 4 N (2) 3 N (3) 5 N (4) 1 N

79. Three blocks are connected as shown in fig. on a horizontal frictionless table if m_1 = 1 kg, m_2 = 8 kg, m_3 = 27 kg and T_3 = 36N, T_2 will be :-



(1) 18 N (2) 9 N (3) 3.375 N (4) 1.75 N

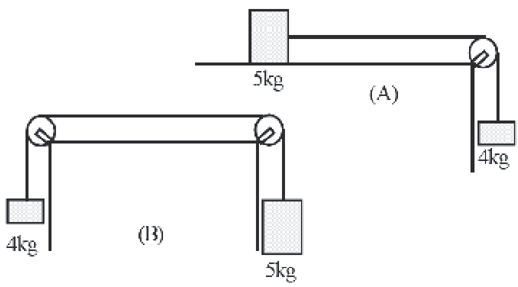
80. In the fig. given below masses m and m' are tied with a thread passing over a pulley, m is on a frictionless horizontal surface. If acceleration due to gravity is g, the acceleration of m' in this arrangement will be :-



(1) g (2) m'g/(m + m')

(3) mg/m' (4) mg/(m - m')

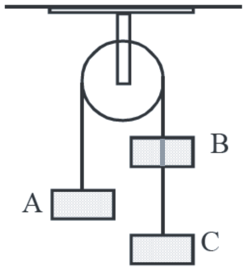
81. Two bodies of masses 5 kg and 4 kg are arranged in two different ways as shown in fig. (A) and (B). If the pulleys and the table are perfectly smooth, the acceleration of the 5 kg body in case (A) and (B) are respectively :-



(1) g and (5/9) g (2) (4/9)g and (1/9)g

(3) g/5 and g/5 (4) (5/9)g aned (1/9)g

82. Three equal weights each of mass 4 kg are hanging on a string passing over a fixed pulley as shown in fig. What is the tension in the string connecting weights B and C.



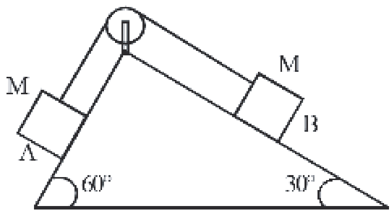
(1) Zero

(2) 13.3 N

(3) 26.6 N

(4) 19.6 N

83. Two blocks each of mass M are resting on a frictionless inclined planes as shown in fig. then



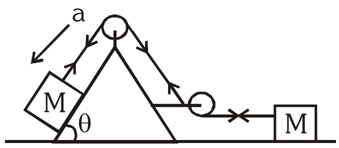
(1) The block A moves down the plane

(2) The block B moves down the plane

(3) Both the blocks remain at rest

(4) Both the blocks move down the plane.

84. Two blocks each having a mass M are placed as shown in the figure. The acceleration of the system is :-



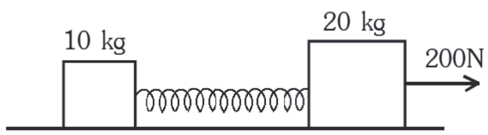
(1) 0

(2) $\dfrac{g\sin\theta}{2}$

(3) $g\sin\theta$

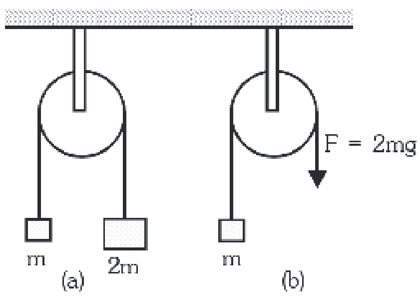
(4) $2g\sin\theta$

85. Two masses of 10 kg and 20 kg respectively are connected by a massless spring as shown in the figure. A force of 200 N acts on the 20 kg mass. At the instant shown the 10 kg mass has an acceleration 4 m/s^2 rightwards. What is the acceleration of 20 kg mass ?



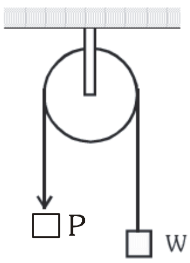
(1) Zero
(2) 10 m/s^2
(3) 4 m/s^2
(4) 8 m/s^2

86. The pulley arrangements shown in the figure are identical, the mass of the rope being negligible. In case (a) mass m is lifted by attaching a mass of 2m to the other end of the rope. In case (b) the mass m is lifted by pulling the other end of the rope with a constant downward force F = 2mg, where g is the acceleration due to gravity. The acceleration of mass m in case (a) is :-



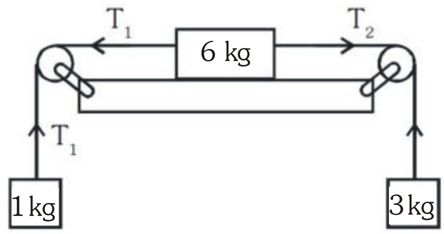
(1) Zero
(2) More than that in case (b)
(3) Less than that in case (b)
(4) Equal to that in case (b)

87. What is the mechanical advantage of single fixed pulley ?



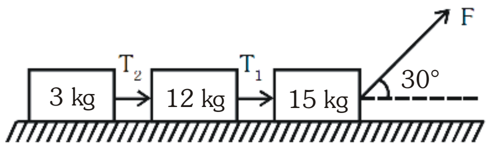
(1) 1 (2) 2 (3) 0.5 (4) 4

88. Three masses of 1 kg, 6 kg and 3 kg are connected to each other with threads and are placed on a table as shown in figure. What is the acceleration with which the system is moving ?
(Take g = 10 m/s^2)



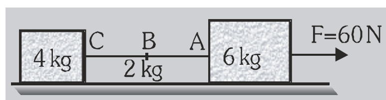
(1) Zero
(2) 2 m/s^2
(3) 4 m/s^2
(4) 3 m/s^2

89. The surface is frictionless, the ratio of T_1 and T_2 is :-



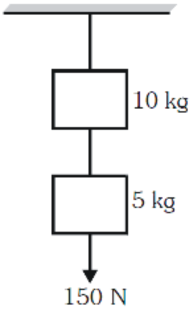
(1) $\sqrt{3} : 1$
(2) $1 : \sqrt{3}$
(3) 1 : 5
(4) 5 : 1

90. Two blocks of masses 6 kg and 4 kg connected by a rope of mass 2 kg are resting on a frictionless floor as shown in the following figure. If a constant force of 60 N is applied to 6 kg block, then the tension in the rope at points A, B and C are respectively given by:



(1) 60 N, 60 N, 60 N
(2) 30 N, 25 N, 20 N
(3) 20 N, 25 N, 30 N
(4) 20 N, 20 N, 20 N

91. Two masses of 10 kg and 5 kg are suspended from a fixed support as shown in figure. The system is pulled down with a force of 150 N attached to the lower mass. The string attached to the support breaks and the system accelerates dowards. If the downward force continues to act, what is the acceleration of the system ?



(1) 20 m/s^2 (2) 10 m/s^2

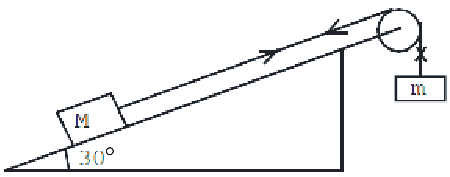
(3) 5 m/s^2 (4) zero

92. A block of mass M is pulled along a horizontal frictionless surface by a rope of mass m. If a force F is applied at one end of the rope, the force which the rope exerts on the block is :-

(1) F/(M + m) (2) F

(3) FM/(m + M) (4) Zero

93. In the fig. mass M = 10 g. is placed on an inclined plane. In order to keep it at rest, the value of mass m will be:



(1) 5 g (2) 10 $\sqrt{3}$ g

(3) 0.10 g (4) $\sqrt{3}$ g

94. The mechanical advantage of a wheel axle is 5. What will be the force required to lift a 200 kg wt?

(1) 10 kg wt. (2) 2 kg wt.

(3) 20 kg wt. (4) 40 kg wt.

95. Two bodies A (30 kg) and B (50 kg) tied with a light string are placed on a frictionless table. A force F acting at B pulls this system with an acceleration of 2ms^{-2}. The tension in the string is :

(1) 60 N (2) 100 N

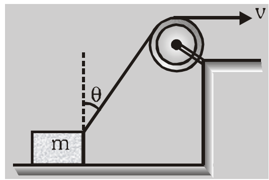
(3) 35 N (4) 140 N

96. A string of length L and mass M is lying on a horizontal table. A force F is applied at one of its ends. Tension in the string at a distance x from the end at which force is applied is

(1) Zero (2) F

(3) F(L - x)/L (4) F(L - x)/M

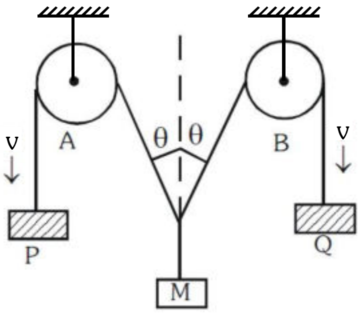
97. A block is dragged on a smooth plane with the help of a rope which moves with a velocity v as shown in figure. The horizontal velocity of the block is :



(1) v (2) $\frac{v}{\sin\theta}$

(3) v sinθ (4) $\frac{v}{\cos\theta}$

98. In the fig., the ends P and Q of an unstrechable string move downward with uniform speed v. Mass M moves upwards with speed.



(1) v cosθ (2) v/cosθ

(3) 2v cosθ (4) 2/v cosθ

FRICTION

99. The coefficient of static friction between two surfaces depend on

(1) the nature of surface

(2) the shape of the surface in contact

(3) the area of contact

(4) all of the above

100. A block of mass 2 kg is placed on the floor. The coefficient of static friction is 0.4. Force of 2.8 N is applied on the block. The force of friction between the block and the floor is

(1) 2.8 N (2) 8.0 N (3) 2.0 N (4) zero

101. The frictional force of the air on a body of mass 0.25 kg, falling with an accleration of 9.2 m/s^2, will be :

(1) 1.0 N (2) 0.55 N

(3) 0.25 N (4) 0.15 N

102. A block of mass 15 kg is placed on a long trolley. The coefficient of friction between the block and trolley is 0.18. The trolley accelerates from rest with 0.5 m/s^2 for 20 s. then what is the friction force ?

(1) 3.5 N (2) 133.3 N

(3) 7.5 N (4) N.O.T.

103. A rope lies on a table such that a part of it hangs down the table. When the length of hanging part is 1/3 of entire length the rope just begins to slide. The coefficient of friction between the rope and the table is :-

(1) 2/3 (2) 1/2

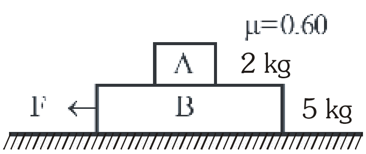
(3) 1/3 (4) 1/6

104. A 2 kg block (A) is placed on 8 kg block (B) which rests on a table. Coefficient of friction between (A) and (B) is 0.2 and between (B) and table is 0.5. A 25 N horizontal force is applied on the block (B), then the friction force between the blocks (A) and (B) is :-

(1) Zero (2) 3.9 N

(3) 5 N (4) 49 N

105. Two blocks (A) 2 kg and (B) 5 kg rest one over the other on a smooth horizontal plane. The coefficient of static and dynamic friction between (A) and (B) is the same and equal to 0.60. The maximum horizontal force F that can be applied to (B) in order that both (A) and (B) do not have any relative motion is :



(1) 42 N (2) 42 kgf

(3) 5.4 kgf (4) 1.2 N

106. A body is placed on an inclined place and has to be pushed down in order to make it move. The angle made by the normal reaction with the vertical will be :-

(1) Equal to angle of repose

(2) Equal to the angle of friction

(3) Less than the angle of repose

(4) More than the angle of friction

107. A car is moving along a straight horizontal road with a speed v_0. If the coefficient of friction between tyres and the road is μ. The shortest distance in which the car can be stopped is :

(1) $\frac{v_0^2}{2\mu g}$ (2) $\frac{v_0^2}{\mu g}$

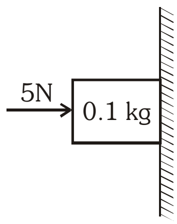
(3) $\left(\frac{v_0}{\mu g}\right)^2$ (4) $\frac{2v_0^2}{\mu g}$

108. The force required to just move a body up an inclined plane is double the force required to just prevent the body from sliding down the plane. The coefficient of friction is μ. The inclination θ of the plane is :-

(1) $\tan^{-1}(\mu)$ (2) $\tan^{-1}(\mu/2)$

(3) $\tan^{-1}(2\mu)$ (4) $\tan^{-1}(3\mu)$

109. A block of mass 0.1 kg. is pressed against a wall with a horizontal force of 5N as shown in the figure. If the coefficient of friction between the wall and the block is 0.5 then the frictional force acting on the block will be ($g = 9.8\ m/s^2$) :-



(1) 9.8 N (2) 2.5 N

(3) 0.98 N (4) 0.49 N

110. A block slides with constant velocity on a plane inclined at an angle θ. The same block is pushed up the plane with an initial velocity v_0. The distance covered by the block before coming to rest is :-

(1) $\frac{v_0^2}{2g\sin\theta}$ (2) $\frac{v_0^2}{4g\sin\theta}$

(3) $\frac{v_0^2\sin^2\theta}{2g}$ (4) $\frac{v_0^2\sin^2\theta}{4g}$

111. A block of mass m is lying on an inclined plane. The coefficient of friction between the plane and the block is μ. The force (F_1) required to move the block up the inclined plane will be:-

(1) mg sinθ + μmg cosθ

(2) mg cosθ – μmg sinθ

(3) mg sinθ – μmg cosθ

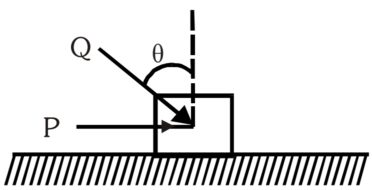
(4) mg cosθ + μmg sinθ

112. A body is sliding down an inclined plane (angle of inclination 45°). If the coefficient of friction is 0.5 and g = 9.8 m/s². then the downward acceleration of the body in m/s² is :-

(1) $\frac{4.9}{\sqrt{2}}$ (2) $4.9\sqrt{2}$

(3) $19.6\sqrt{2}$ (4) 4.9

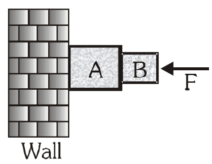
113. A block of mass m lying on a rough horizontal plane is acted upon by a horizontal force P and another force Q inclined at an angle θ to the vertical. The block will remain in equilibrium if the coefficient of friction between it and the surface is :-



(1) $\frac{P+Q\sin\theta}{mg+Q\cos\theta}$ (2) $\frac{P\cos\theta+Q}{mg-Q\sin\theta}$

(3) $\frac{P+Q\cos\theta}{mg+Q\sin\theta}$ (4) $\frac{P\sin\theta+Q}{mg-Q\cos\theta}$

114. Adjoining figure shows two blocks A and B pushed against the wall with a force F. The wall is smooth but the surfaces in contact of A and B are rough. Which of the following is true for the system of blocks to be at rest against the wall ?



(1) F should be be more than the weight of A and B

(2) F should be equal to the weight of A and B

(3) F should be less than the weight of A and B

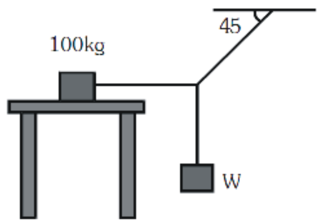
(4) system cannot be in equilibrium

115. A body of mass 100 g is sliding on a inclined plane with an inclination of 60⁰. What is the fricitional force experienced, if coefficient of friction is 1.7 ? (Take g = 10 m/s²)

(1) 0.85 N (2) 0.95 N

(3) 1.05 N (4)1.145 N

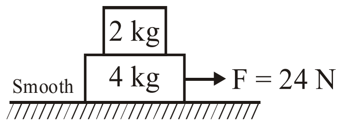
116. The system shown in the figure is in equilibrium. The maximum value of W, so that the maximum value of static frictional force on 100 kg body is 450 N, will be :-



(1) 100 N (2) 250 N

(3) 450 N (4)1000 N

117.



In the arrangement coefficient of friction between the two blocks is $\mu = \frac{1}{2}$. The force of friction acting between the two blocks is :-

(1) 8 N (2) 6 N

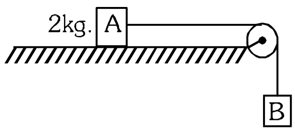
(3) 10 N (4) 12 N

118. A block has been placed on an inclined plane with the slope angle θ, the block slides down the plane at constant speed. The coefficient of kinetic friction is equal to :-

(1) sinθ (2) cosθ

(3) g (4) tanθ

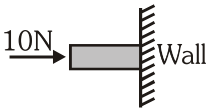
119. The coefficient of static friction, μ_s, between block A of mass 2 kg and the table as shown in the figure is 0.2. What would be the maximum mass value of block B so that the two blocks do not move ? The string and the pulley are assumed to be smooth and massless. (g = 10 m/s²)



(1) 4.0 kg (2) 0.2 kg

(3) 0.4 kg (4) 2.0 kg

120. A horizontal force of 10 N is necessary to just hold a block stationary against a wall. The coefficient of friction between the block and wall is 0.2. The weight of the block is :-



(1) 20 N (2) 50 N (3) 100 N (4) 2 N

121. A given object takes n times as much time to slide down a 45^0 rough incline as it takes to slide down a perfectly smooth 45^0 incline. The coefficient of kinetic friction between the object and the incline is given by :

(1) $\left(1-\frac{1}{n^2}\right)$ (2) $\left(\frac{1}{1-n^2}\right)$

(3) $\sqrt{\left(1-\frac{1}{n^2}\right)}$ (4) $\sqrt{\left(\frac{1}{1-n^2}\right)}$

EXERCISE-I (Conceptual Questions) ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ans.	**3**	**2**	**1**	**1**	**1**	**2**	**2**	**3**	**3**	**3**	**2**	**2**	**4**	**3**	**2**
Que.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Ans.	**3**	**1**	**3**	**2**	**3**	**1**	**1**	**1**	**2**	**1**	**3**	**1**	**1**	**1**	**1**
Que.	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Ans.	**2**	**3**	**3**	**1**	**3**	**1**	**2**	**3**	**4**	**2**	**2**	**2**	**2**	**2**	**4**
Que.	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Ans.	**3**	**4**	**4**	**1**	**3**	**1**	**3**	**3**	**3**	**3**	**4**	**4**	**3**	**4**	**1**
Que.	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Ans.	**1**	**2**	**2**	**2**	**1**	**1**	**2**	**1**	**3**	**4**	**3**	**3**	**2**	**2**	**1**
Que.	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Ans.	**4**	**3**	**4**	**2**	**2**	**2**	**3**	**1**	**2**	**4**	**3**	**1**	**2**	**4**	**2**
Que.	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
Ans.	**1**	**3**	**1**	**4**	**1**	**3**	**2**	**2**	**1**	**1**	**4**	**3**	**2**	**1**	**1**
Que.	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
Ans.	**3**	**1**	**4**	**3**	**2**	**1**	**1**	**1**	**4**	**1**	**3**	**1**	**4**	**3**	**4**
Que.	121														
Ans.	**1**														

EXERCISE-II (Assertion & Reason)

Directions for Assertion & Reason questions

These questions consist of two statements each, printed as Assertion and Reason. While answering these Questions you are required to choose any one of the following four responses.

(A) If both Assertion & Reason are True & the Reason is a correct explanation of the Assertion.

(B) If both Assertion & Reason are True but Reason is not a correct explanation of the Assertion.

(C) If Assertion is True but the Reason is False.

(D) If both Assertion & Reason are false.

1. **Assertion :** The driver in a vehicle moving with a constant speed on a straight road is in a non-inertial frame of reference. **[AIIMS 2004]**

Reason : A reference frame in which Newton's laws of motion are applicable is non-inertial.

(1) A (2) B (3) C (4) D

2. **Assertion:** A man in a closed cabin falling freely experience weightlessness.

Reason: Inertial and gravitational mass have equivalence. **[AIIMS 2006]**

(1) A (2) B (3) C (4) D

3. **Assertion :-** Animate object can accelerate in the absence of external force.

Reason :- Newton's second law is not applicable on animate object. **[AIIMS 2012]**

(1) A (2) B (3) C (4) D

4. **Assertion :** A body can be at rest even when it is under the action of any number of external forces.

Reason : Vector sum of all the external forces on a body may be zero.

(1) A (2) B (3) C (4) D

5. **Assertion :** The weighing machine measures the weight of a body.

Reason : Weightlessness means the absence of weight.

(1) A (2) B (3) C (4) D

(**Note:** The weighing machine measures the reaction between the machine and the body and weightlessness usually means absence of reaction between the body and that with which it is in contact.)

6. **Assertion :** Pseudo force is an imaginary force which is recognised only by a non-inertial observer to explain the physical situation according to Newton's laws.

Reason : Pseudo force has no physical origin, that is, it is not caused by one of the basic interactions in nature. It does not exist as on action-reaction pair.

(1) A (2) B (3) C (4) D

7. **Assertion :** A table cloth can be pulled from a table without dislodging the table.

Reason : For a moving object, if its speed changes, its velocity must change and it must have some acceleration.

(1) A (2) B (3) C (4) D

8. **Assertion :** The apparent weight of a person standing in a lift which moves upwards with uniform acceleration is always higher than his true weight.

Reason : The weight (on the earth surface) always acts downwards.

(1) A (2) B (3) C (4) D

9. **Assertion :** Mass is a property of one object alone, whereas weight results from the interaction between two objects.

Reason : The weight of an object is proportional to its mass.

(1) A (2) B (3) C (4) D

10. **Assertion :** Every mutual interaction between two bodies always follow the action–reaction law.

Reason : Single isolated force without reaction is not possible

(1) A (2) B (3) C (4) D

11. **Assertion :** Newton's second law of motion gives the measurement of force.

Reason : According to Newton's second law of motion, force is directly proportional to the rate of change of momentum.

(1) A (2) B (3) C (4) D

12. **Assertion :** Pulling a lawn roller is easier than pushing it.

Reason : Pushing increases the apparent weight and hence the force of friction.

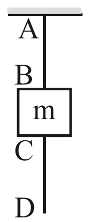
(1) A (2) B (3) C (4) D

13. **Assertion :** A man who falls from a height on a cemented floor receives more injuries than when he falls from the same height on a heap of sand.

Reason : The impulse applied by the cemented floor is more than the impulse by sand heap.

(1) A (2) B (3) C (4) D

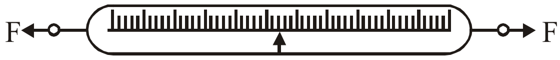
14. **Assertion :** The cord between A and B is more likely to snap due to a continuous downward pull at D.



Reason : When someone gives the lower cord a sudden downward pull, the tension in the lower cord increases suddenly.

(1) A (2) B (3) C (4) D

15. **Assertion :** When a spring balance is pulled by two forces of equal magnitude and opposite directions, its reading must be non-zero.



Reason : For the spring balance, shown the net force acting on the balance is zero.

(1) A (2) B (3) C (4) D

16. **Assertion :** A player lowers his hands while catching a cricket ball.

Reason : This increases the time of catch.

(1) A (2) B (3) C (4) D

17. **Assertion :** In karate, a brick is broken with a bare hand.

Reason : In this process the impulse is sharp.

(1) A (2) B (3) C (4) D

18. **Assertion :** On a rainy day, it is difficult to drive a car or bus at high speed.

Reason : The value of coefficient of friction is lowered due to wetting of the surface. **[AIIMS 1995/99]**

(1) A (2) B (3) C (4) D

19. **Assertion:** Angle of repose is equal to the angle of limiting friction.

Reason: When the body is just on the verge of motion, the force of friction in this stage is called limiting friction. **[AIIMS 2008]**

(1) A (2) B (3) C (4) D

20. **Assertion :** Force of friction depends on the area of contact.

Reason : Larger the area of contact, larger is the opposition to motion.

(1) A (2) B (3) C (4) D

21. **Assertion :** Static frictional force is a self adjusting force.

Reason : Force of static friction does not depend upon the mass of the body.

(1) A (2) B (3) C (4) D

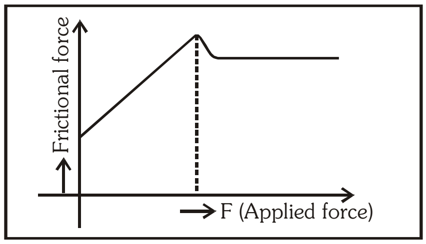
22. **Assertion :** Frictional force is the component of contact force parallel to the surface.

Reason : Friction force always opposes the motion of a body.

(1) A (2) B (3) C (4) D

23. **Assertion :** Friction is a self-adjusting force.

Reason : A block on the horizontal table is acted upon by a force F. The graph of frictional force against applied force F is.



(1) A (2) B (3) C (4) D

24. **Assertion:** A body of weight W = 10N is at rest on an inclined plane $\left(\mu = \frac{\sqrt{3}}{2}\right)$ making an angle of 30° with the horizontal. The force of friction acting on it is 5N.

Reason : In the above situation, limiting force of friction is given by $f_{limiting} = \mu W\cos\theta = 7.5$ N.

(1) A (2) B (3) C (4) D

25. **Assertion :** When a force $\vec{F}$ attempts to slide a body along a surface, a frictional force parallel to the surface and directed so as to oppose the sliding, is exerted on the body by the surface.

Reason : It is due to the bonding between the body and the surface.

(1) A (2) B (3) C (4) D

26. **Assertion** : The force of tension on a body always acts away from the body.

Reason : Friction force always opposes the motion of a body.

(1) A (2) B (3) C (4) D

27. **Assertion :** Static friction is self adjusting but kinetic friction is a constant force for a certain range of speed.

Reason : A body slides down an inclined plane if the angle of friction is more than the angle of the inclined plane with the horizontal.

(1) A (2) B (3) C (4) D

28. **Assertion :** Magnitude of the contact force is always greater than the magnitude of frictional force.

Reason : Contact force is the resultant of the friction force and normal reaction.

(1) A (2) B (3) C (4) D

29. **Assertion :** When a person walks on a rough surface, the frictional force exerted by the surface on the person is opposite to the direction of the tendency of motion of his legs.

Reason : If a body moves with constant velocity, it implies that it is moving along a straight line and there is no acceleration.

(1) A (2) B (3) C (4) D

30. **Assertion :** The acceleration of a body down a rough inclined plane is greater than the acceleration due to gravity.

Reason : A body is able to slide on an inclined plane only when its acceleration is greater than the acceleration due to gravity. **[AIIMS 2007]**

(1) A (2) B (3) C (4) D

31. **Assertion :** A block of mass m is kept at rest on an inclined plane, the force applied by the surface to the block will be mg.

Reason : Contact force between block and inclined plane is the resultant of normal reaction and frictional force.

(1) A (2) B (3) C (4) D

32. **Assertion :-** Trajectory of a particle depends only on force acting on it.

Reason :- Velocity & position of a particle depends only on force acting on it. **[AIIMS 2015]**

(1) A (2) B (3) C (4) D

33. ***Assertion :-*** If ball is dropped from a higher altitude. There will be a greater value of impulse from ground during collision. **[AIIMS 2017]**

Reason :- Gravity increases momentum of a ball.

(1) A (2) B (3) C (4) D

34. ***Assertion :-*** When man walks on a flat surface, normal reaction remains constant during the process. **[AIIMS 2018]**

Reason :- Total upward force acting on man perpendicular to surface is equal to the weight of man.

(1) A (2) B (3) C (4) D

35. ***Assertion :-*** Sliding friction doesn't depend on area of contact. **[AIIMS 2018]**

Reason :- Actual atomic surface area is very less than apparent area of contact.

(1) A (2) B (3) C (4) D

36. ***Assertion :-*** A batsman is protected from injury by wearing helmet. **[AIIMS 2018]**

Reason :- Helmet prolongs the time of impact.

(1) A (2) B (3) C (4) D

EXERCISE-II (Assertion & Reason) ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ans.	**4**	**1**	**4**	**1**	**4**	**1**	**2**	**2**	**2**	**1**	**1**	**1**	**3**	**2**	**2**
Que.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Ans.	**1**	**1**	**1**	**2**	**4**	**2**	**3**	**4**	**2**	**1**	**3**	**3**	**1**	**2**	**4**
Que.	31	32	33	34	35	36									
Ans.	**1**	**4**	**1**	**4**	**1**	**1**									